

LOS ALAMOS SCIENCE AND TECHNOLOGY MAGAZINE

MARCH 2011

# 1663

Extrasolar planet migration

Quantum encryption

Vaccine strategy for HIV

Global security challenge



**About Our Name:** During World War II, all that the outside world knew of Los Alamos and its top-secret laboratory was the mailing address—P. O. Box 1663, Santa Fe, New Mexico. That box number, still part of our address, symbolizes our historic role in the nation's service.

**About the LDRD Logo:** Laboratory Directed Research and Development (LDRD) is a competitive, internal program by which Los Alamos National Laboratory is authorized by Congress to invest in research and development that is both highly innovative and vital to our national interests. Whenever 1663 reports on research that received support from LDRD, this logo will appear at the end of the article.

**About the Cover:** People can get infected by any of several thousand genetically distinct versions of HIV, the virus that causes AIDS. This extraordinary viral diversity has so far prevented the discovery of an effective vaccine. But a potential new vaccine, based on engineered "mosaic" proteins developed by Los Alamos researchers, is being tested in Phase I human trials. The cover image expresses the hope that these new proteins, shown forming a protective line against encroaching viruses, can save lives and help ease the global HIV pandemic.



LOS ALAMOS ARCHIVE

Two members of the Special Engineering Detachment, Ray Brin and Phil Daley, stand next to a shake-test stand containing a dummy unit stand-in for the bomb known as Fat Man.



## My View

### Broader Impacts

*This issue of 1663 highlights the sometimes surprising ways in which our enduring national security missions—the reasons why the nation continues to turn to Los Alamos—are enriched by the strength of our technical capabilities. These capabilities, including those in the areas of materials science, predictive*

*modeling and simulation, and the science of signatures, were developed to address difficult national security challenges but often have wider unanticipated benefits for society. Our ability to realize these broader impacts at a national security laboratory is a key reason that the next generation of scientists will choose a career at Los Alamos.*

*The effects of turbulence and shock waves are fundamentally important to understanding the performance of nuclear weapons, and our ability to simulate these effects with confidence is increasingly important in a world with fewer nuclear weapons and without nuclear testing. At a cosmic scale, these effects also dictate the dynamics of the formation of planets in solar systems. Recent discoveries have proven that our galaxy has a much richer variety of planetary systems than previously known. Our simulations explore the physics underlying this diversity.*

*Our ability to use the most advanced science and engineering to keep our vital information secure has led to a breakthrough in cryptography, using quantum key distribution. This encryption system is simple yet theoretically unbreakable because it uses the inherent features of quantum measurement coupled with advanced optical signal processing. This encryption system is not only a*

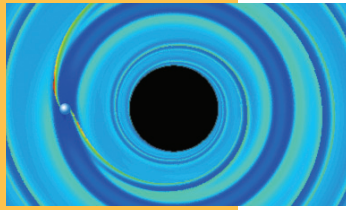
*technological breakthrough but also a commercial prototype that may revolutionize the security of Internet communications.*

*Advanced computing research performed on Los Alamos supercomputers to address biosecurity challenges, dating back to before the Human Genome Project, has continued to thrive here, most recently serving as a means of testing the capabilities of the first petaflop-class hybrid supercomputer, Roadrunner. As part of last year's Roadrunner computing challenge, a team of scientists constructed a phylogeny tree tracing the evolution of the human immunodeficiency virus (HIV) since it first emerged in the early 1980s. In this issue, we learn how these capabilities are now being applied to design the first HIV vaccine developed and optimized completely by computer. This advance offers the best current hope of vanquishing the world's most deadly human infectious disease, responsible for killing 2 million people every year.*

*This issue also features the interplay between capability and mission in global security, climate science, nanotechnology, and our electronic research library. Our ability to sustain such a diversity of vibrant science and engineering, while also delivering solutions to national security problems, remains a distinguishing feature of Los Alamos National Laboratory.*

Charles McMillan,  
Principal Associate Director  
for Weapons Programs

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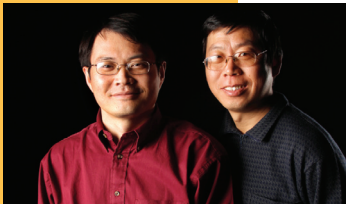


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CHARLES MCMILLAN, PRINCIPAL ASSOCIATE DIRECTOR FOR WEAPONS PROGRAMS

Broader Impacts

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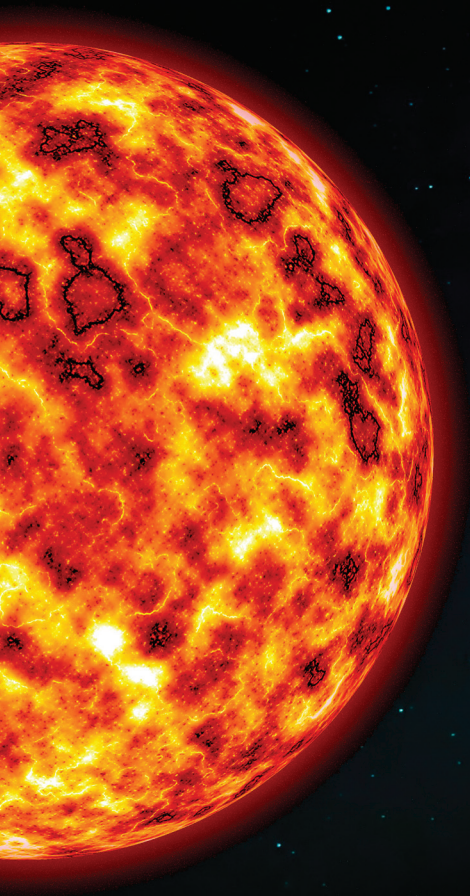
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# Wandering Worlds

*Saving newborn planets from a fiery demise is just one step in the quest to understand the mysterious planetary systems around other stars.*



Hui Li (left) and Shengtai Li study the forces affecting the complicated evolution of newborn planetary systems.



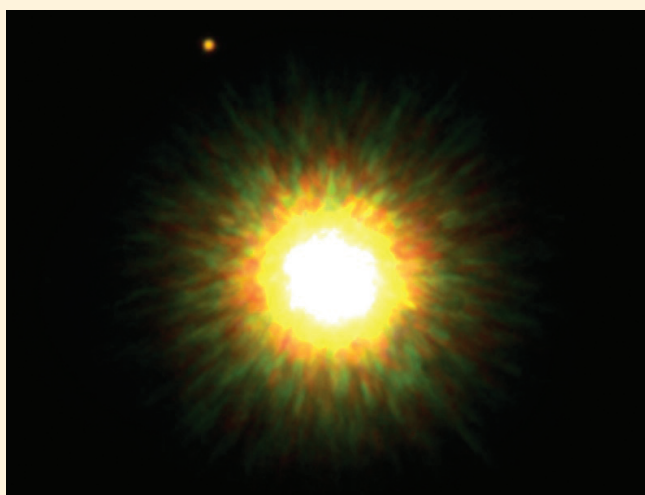
**Before 1995**, it was widely assumed that other planetary systems would be like ours. Small rocky planets like Venus and Earth would live near their sun. Large gaseous planets like Jupiter and Saturn would live farther out. And all of them would have nearly circular orbits. Never mind the fact that, at that time, there was no observational evidence for the existence of even a single planet orbiting another Sun-like star. (A few appeared to orbit around pulsars, but pulsars are generally considered to be “dead” stars.)

Perhaps that evidence seemed too difficult to come by. Detecting a dim and comparatively tiny planet right next to a much bigger and brighter object—its parent star—many light years away would be like spotting a dust grain next to a jet airliner glinting in the Sun at 37,000 feet.

Or perhaps the evidence for other planets didn't seem necessary. Our solar system made so much sense that you could simply *expect* others like ours to exist. According to standard theory, our solar system (and presumably others) began with the young Sun at the center of a swirling disk of gas and dust. Over time, gravity caused the dust to accumulate to form the cores of emerging planets, which then kept roughly the same nearly circular orbits that the disk material had. Near the Sun, the disk is too hot and lacks sufficient gas to form giant planets. Only farther away could you get a gas giant resembling Jupiter. And just like that, you've built a solar system with nothing more than basic physics: gravity, Newtonian motion, and a little thermodynamics. What could be wrong with that?

### Pesky Planets

Unfortunately, all it takes is one good measurement to spoil a perfectly sensible theory. In 1995, astronomers discovered the first of what would grow to be a whole fleet of planets outside of our solar system—extrasolar planets, or exoplanets for short. (At the time of this writing, 528 exoplanets have been confirmed.) This first exoplanet, discovered around a Sun-like star called 51-Pegasi, turned out to be a gas giant at least half the mass of Jupiter, but the size of its orbit is one-sixth that of our Sun's innermost



Most extrasolar planets are too dim to see with today's technology. But in this image, an infrared telescope was able to reveal an exoplanet (top left) together with its parent star, because the planet hasn't yet cooled from its initial formation.

CREDIT: GEMINI OBSERVATORY, D. LAFRENIERE, R. JAYAWARDHANA, M. VAN KERKWIJK (UNIVERSITY OF TORONTO).

planet, Mercury. And a year on this exoplanet lasts only four Earth days. Perhaps researchers imagined that 51-Pegasi's planet would prove to be a rare oddity in an otherwise sensible galaxy. Instead, hundreds of similar exoplanets have since been discovered, implying that such “hot jupiters” are the rule, not the exception.

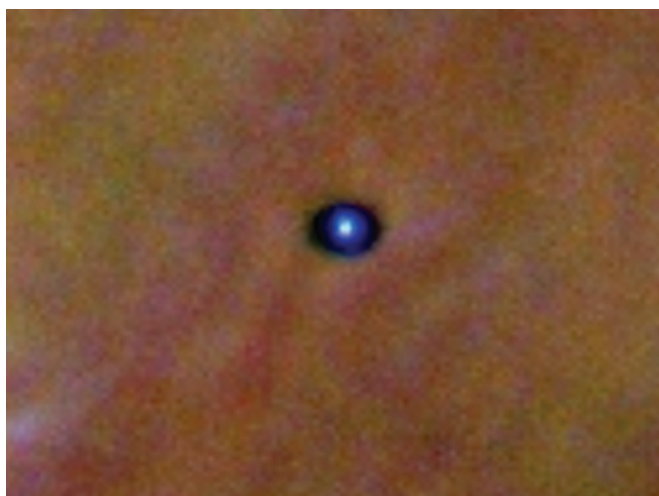
To be fair, astronomers admit that their prevailing planet detection method is biased in favor of finding massive planets orbiting close to their stars, because such planets have a strong gravitational effect on their stars, and that effect is what's

observed. Planetary systems like our own, with only small planets near the Sun and massive planets far away, would generally go unnoticed. Nonetheless, whether hot jupiters are genuinely common, or just selectively picked up by the biased methodology, many do exist. They are pervasive and need to be explained.

The trouble is, attempts to explain hot jupiters lead to other vexing questions. Because gas giants can't form in the heat near a star the most logical possibility is that these planets formed in cooler regions away from the star and then somehow moved inward. This is called *migration*. Scientists began to explore migration by calculating how a surrounding disk of matter might pull a planet inward. They found that migration should indeed happen, but would happen so quickly that a planet would move all the way inward, even into the central star, long before its orbit could stabilize (the way Earth's orbit is stable now). Even our own Earth should not exist.

Clearly, some other factor is at work here. Something must be saving planets from migrating into their suns. But what is that something? Scientists have proposed several new mechanisms, including the effects of magnetic fields, turbulent motions, or altered densities in the disk. One or more of these ideas may indeed do the trick. But here at Los Alamos National Laboratory, astrophysicist Hui Li and computational scientist Shengtai Li (no relation) have conducted high-resolution supercomputer simulations of another possibility—one that shows just how these planets might naturally be saved under realistic conditions in the disk.





Planets are born from a disk of gas and dust swirling around a young star, like this one. The disk appears black because its dust obscures light coming from behind it.

CREDIT: D. JOHNSTONE (CITA), J. BALLY (U. COLORADO) ET AL., WFPC2, HST, NASA.

## Shock and Stall

A planet migrates as a result of a complex interaction between the planet and the gas in the disk. The planet's gravity disturbs the material in the disk, creating two density waves—one propagating inward and the other propagating outward. Because of standard differential rotation, in which orbiting matter revolves faster when it's closer to the center, the disturbances wrap into spirals. These spiral waves are visible in the output from the Los Alamos team's simulations (see figure below).

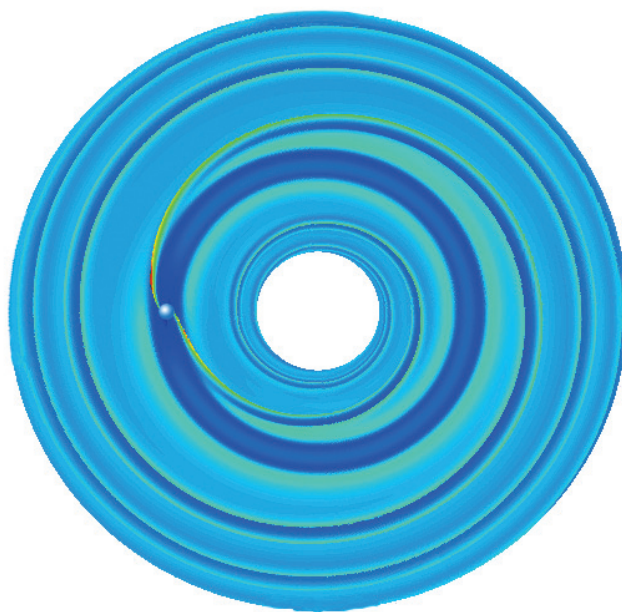
The waves gravitationally tug on the planet but will only cause the planet to migrate inwards if the interaction permanently drains angular momentum from the planet's orbit. (Angular momentum is momentum associated with motion around an axis.) That means the waves must dissipate angular momentum into the disk. This happens naturally if the disk has sufficient resistance to flow—that is, if it has enough viscosity. Unfortunately, the disk around a young star is made from a very dilute gas, so it has very little viscosity in the normal sense: it's not at all sticky like honey. What it does have, as has long been postulated, is *turbulent viscosity*, resulting from the gas thickening in some regions, thinning in others, and moving about and mixing in a haphazard way. Thus, the amount of migration depends on how turbulent the disk is.

In this simulation, a planet (at the 9-o'clock position) has gravitationally disturbed the surrounding disk, creating waves that propagate inward and outward. The rotation of the disk material is faster toward the center, so the waves wrap around into the spiral seen here. Red and yellow indicate higher density, as seen in the spiral waves. Blue indicates lower density, as seen in the circle of the planet's orbit, from which the planet has already driven disk material away.

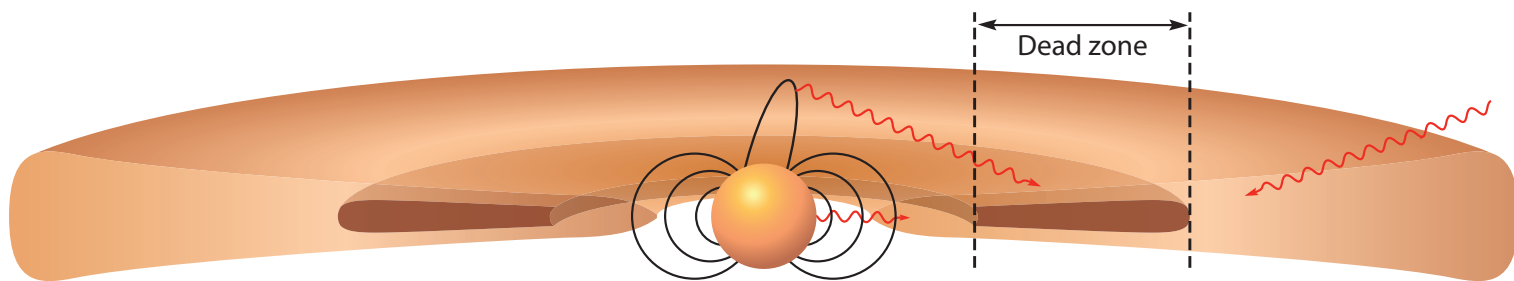
Conventional models portray the disk as plenty turbulent: migration is rapid, and planets don't survive. But there are hints that the turbulence may be lower. Some observations of young stars support this possibility. If so, then the lower turbulence would lead to lower viscosity. A less viscous disk would dissipate less of the planet's orbital angular momentum, leading to slower migration. In fact, Li and Li's research has shown that the nature of the dissipation becomes quite different in a low-viscosity disk.

The spiral waves that drain and dissipate angular momentum from a planet's orbit are actually shock waves—waves that travel faster than the speed of sound. That is to be expected, because the cold, dilute gas in the disk has a relatively slow sound speed. The spiral shock waves cause an irreversible exchange of angular momentum between the planet and the disk material. Normally, this shock-based dissipation is a minor effect when compared to the viscous dissipation. But the simulations reveal that if the viscosity is about one-tenth the value that conventional disk models suppose, then shock dissipation produces a greater angular momentum exchange than viscous dissipation. In that case, migration mediated by shock waves determines a planet's fate.

The simulations reveal that the amount of time needed for migration dominated by shock physics in a low-viscosity disk is appreciably longer than the time needed for viscous migration in a conventional disk. The actual time depends







on the mass of the planet, but the result is generally ten million to a hundred million years ( $10^7$  to  $10^8$ )—much longer than the hundred thousand years ( $10^5$ ) suggested by higher-viscosity simulations. The extended time afforded by the low-viscosity scenario is long enough, because even though stars like the Sun live for several billion years ( $10^9$ ), the disk around a young star only survives for about  $10^7$  years. The disk will vanish by photoevaporation under the intense radiation of the parent star, allowing the planet's orbit to stabilize before the planet migrates all the way inward. Once the disk is gone, so is the tendency for planets to migrate.

So it seems that Li and Li have solved the migration problem, if indeed the disks that form around young stars have very little turbulent viscosity. In theory, this should be the case within a disk's dead zone, the part of the disk where ultraviolet radiation from the central star, and other high-energy radiation from elsewhere, do not reach (see figure above). Ultraviolet radiation is energetic enough to ionize the gas in the disk, causing electrons to abandon their atoms. The resulting charged ions and electrons, unlike electrically neutral atoms, are affected by magnetic fields in the disk, so they enable magnetic forces to stir the gas and generate the turbulence that gives rise to turbulent viscosity. The dead zone, however, being shielded from ionizing radiation, would have far less turbulence. Planets formed in the dead zone would suffer only shock-based migration forces, saving them from an untimely demise.

### Not Exactly Physics 101

Evidently, understanding the dynamics of exoplanetary systems requires a detailed understanding of the intricate physical processes involved. But even with simulations of shock waves and calculations of turbulent viscosity, much remains unknown. For example, how would adding a third, vertical dimension to the simulations affect the results? How would spiral density waves propagate and steepen into shocks in such systems? And what about more complex disks? Might different amounts of dissipation at different locations occasionally tip the delicate balance of gravitational influences, sometimes causing young planetary bodies to migrate outward instead of inward?

In the dead zone—the region of a disk that's shielded from ionizing radiation (wavy arrows)—the disk's viscosity is much lower. As a result, turbulence in the disk's surface layers has a diminished influence over the motion of a planet in this region, essentially eliminating the planet's migration. Sources of ionizing radiation include the star, the magnetically active region around the star, and cosmic rays from the rest of the galaxy.

Even if such improvements are made to the simulations, the original dilemma persists: the existence of gas giant planets demands that the Earth-sized planetary cores from which they grew must have been surrounded by an abundance of gas, yet this very abundance of gas significantly increases their migration rate and thereby threatens their survival. Figuring out how to slow down the migration becomes a trickier business when you're trying to make the planet grow at the same time.

While the work of Li and Li and others in the field appears to explain how the migration of Earth-sized cores can be stopped, young planetary systems are still quite complex. Other key processes that operate over the same time span as the slowed planetary core migration include the formation of gas giants by accumulating the surrounding gas and the photoevaporation of that gas by the central star. Thus, the interplay of three essential processes—planet formation, planet migration, and disk evaporation—must conspire in complex ways to produce the vast diversity of exoplanet masses and orbital properties detected so far. This interplay begs for further research with ever-more-sophisticated simulations, which Li and Li already have underway.

In one generation, exoplanets have gone from little more than a mainstay of science fiction to a richly varied reality. While a complete picture of their evolution remains elusive, Li and Li and others in the exoplanet astrophysics community are hopeful that these enigmatic extraterrestrial systems are destined to be understood. ❖ **LDRD**

— Craig Tyler





# ***Secure Communication Now and Forever***

Quantum cryptography for the consumer



0

**Valuable information**, personal information, secret information—each is transmitted all around you, all the time. To prevent that information from reaching thieves, spies, and terrorists, it is encrypted, with the intent of rendering it indecipherable to everyone except its intended recipient. And encryption, or more generally, cryptography—the science of encoding information—stands on the verge of a technological revolution.

Encryption usually involves one or more secret keys—numbers used in some mathematical operation to protect the sensitive information. For example, suppose the message to be sent is the number 4, the key is the number 3, and the encryption scheme is simple multiplication. Then the encrypted message is 12 (because  $4 \times 3 = 12$ ). The receiver would divide the transmitted number, 12, by the key, 3, to recover the original number, 4. In a more realistic application, the key could be hundreds of digits long and use an algorithm much more sophisticated than simple multiplication. Either way, without the key, you can't unlock the information.

But what if you could calculate the key? Perhaps you could use an algorithm to test lots of different numbers until you hone in on the right one. This is indeed possible. The security of conventional encryption relies on the mathematical difficulty, not the impossibility, of calculating the key. An encryption scheme might be considered secure if the fastest computers in existence today would take decades, say, to break it. The point is, it can be broken. It's just a matter of time until the available computing power becomes sufficient. "You're betting against technology," says Los Alamos physicist and quantum communications team member Raymond Newell. "That's not a safe bet."

A sender prepares, and a receiver measures, the polarization of photons (particles of light) with respect to a randomly chosen orientation, either  $\uparrow$  or  $\times$ . The laws of quantum physics ensure that the sender and receiver will measure the same polarization direction when they use the same measurement orientation. Otherwise, whether their measurements agree or not is completely random. By comparing openly their randomly chosen measurement orientations (but not their actual measurement results), they can identify which polarization outcomes they hold in common. A secret encryption key, known only to the two of them, can be built from this information.

DISCOVER MasterCard VISA American Express [Why this is safe]

Card Number:

Expiration Date: 03/2011

Validation Code:

**Pay Now**

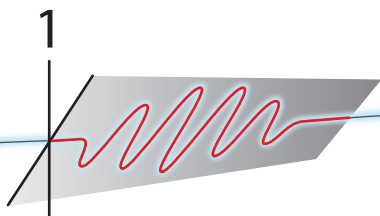
"Why this is safe," or "Whether this is safe"? Conventionally encrypted transmissions rely on mathematical complexity: with current computing technology, it could take decades to break these codes. But they can be broken.

Fortunately, practical quantum cryptography, which includes encryption schemes that neither today's computers nor future computers can defeat, has arrived. Building on 17 years of basic and applied research and a long string of experimental breakthroughs, Los Alamos scientists Jane Nordholt, Richard Hughes, Raymond Newell, and Glen Peterson have designed and built a handheld quantum cryptography system for the consumer. The system creates and shares, on demand, an encryption key between a sender and receiver. It then uses a transmission protocol based on quantum physics to ensure that the key can never be harmfully intercepted. And unlike a classical key, a quantum key cannot be revealed through calculation. This technology is currently being offered for license to the private sector to be used for everyone's benefit, making encrypted transmissions secure into the future.

### Quantum Measurements

The Los Alamos team based its work on the BB84 protocol, first published in 1984 by Charles Bennett and Gilles Brassard. It uses the inherent randomness of quantum measurements to piggyback information on a beam of light. To appreciate the BB84 method, it is important to know a little about quantum physics.

Quantum physics is often thought of as the science of the very small. It deals with individual particles, like electrons or photons (particles of light). Unlike classical (nonquantum) physics, quantum physics is intrinsically probabilistic, meaning that, in general, the outcome of any one measurement cannot be definitively predicted. The



best you can do is predict the probabilities associated with different possible outcomes. If you measure the same type of particle in the same way 100 times, and you get the same outcome in 30 of those measurements, then the probability of that outcome is evidently around 30 percent. That probability can be calculated in advance, but the result of any individual measurement cannot.

The inherent unpredictability of quantum measurements provides a benefit for secure communications because it makes each quantum key unpredictable. If a classical key and its associated algorithm were to somehow get into enemy hands, that enemy could run the algorithm backward to acquire the keys used in the past, and forward to compute future keys. But if a quantum key were ever compromised, it would be no help in generating other keys.

The BB84 protocol is most often implemented by measuring the polarization of individual photons. Because light is an electromagnetic wave, photons have an intrinsic orientation, like the poles of a magnet. That direction oscillate along a particular axis. A classical polarization

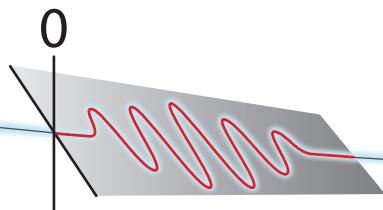
experiment might seek to determine along which axis a beam of light is polarized. But in a quantum measurement—one photon at a time—the best you can do is choose an axis, make your measurement, and get an answer of “yes” (the photon is polarized along the axis you chose) or “no” (it’s polarized perpendicular to your axis). Quantum polarization measurements admit no middle ground.

For example, suppose you have a vertically polarized photon. (This means that its electrical orientation alternately points up and down as the light travels forward.) You measure its polarization along a particular axis. A vertical axis measurement like  $\updownarrow$  would come back “yes.” A horizontal axis measurement like  $\leftrightarrow$  would come back “no.” But a diagonal axis tipped like  $\nearrow$  could come back “yes” or “no” with different probabilities. If the axis is tipped 45 degrees, the probabilities are 50/50, so half of these measurements would be “yes” and the other half “no.” But quantum measurements have the additional property of changing the object being measured. If your diagonal polarization experiment returns “yes,” then that photon’s polarization changes to  $\nearrow$ ; it’s no longer vertical. If you get “no,” the polarization is now exactly opposite, 45 degrees the other way, like  $\searrow$ . Either way, the act of measurement altered the photon’s polarization.



The Los Alamos quantum communications team rests easy, knowing that their inventions will protect consumers’ personal information. (From the left: Raymond Newell, Glen Peterson, Jane Nordholt, and Richard Hughes.)





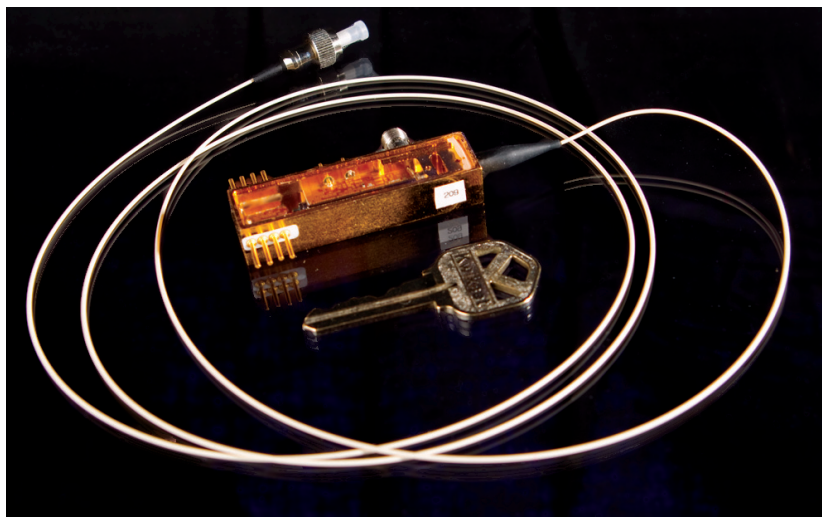
This behavior of quantum measurements plays a critical role in quantum cryptography, and it is completely different from classical measurements. For example, if you're driving a "quantum car" past a police officer who measures your speed with a radar gun, that measurement would return a random (probabilistic) value. If it happens to read 90 mph, then your car would suddenly jump to 90 mph! For cryptography, this quantum behavior is valuable because measurements made by an unauthorized individual will randomly change the original transmission, just as the radar measurement changed your speed. The sender and receiver, upon comparing notes, will be able to tell if the transmission is being tampered with before any sensitive information is sent.

### Agree on the Key

A key is used by the sender to encode a message, and again by the receiver to decode it. The first transmission, therefore, establishes a key (or two related keys) that both sender and receiver must agree upon. Then, if the key is proven to be secure, it is used to encode the message, and the encoded message is sent.

Imagine a sender named Alice and a receiver named Bob. To establish a key, Alice first prepares a series of specially polarized photons to send to Bob. To do this, she considers two possible sets of orientations: either horizontal and vertical ( $\pm$ ) or positive and negative 45-degree diagonals ( $\times$ ). She also assigns bit values for each orientation; perhaps horizontal is 0 while vertical is 1, and diagonally leaning left is 0 while diagonally leaning right is 1. (These bit assignments are not secret, and Bob will need to use them too.) As Alice generates each photon, she randomly selects an orientation and bit value. This creates a series of polarized photons with orientations, for example,  $- / \backslash$ , and corresponding bit values 01101. Then she waits to hear from Bob.

Bob randomly chooses a measurement orientation ( $\pm$  or  $\times$ ) for each incoming photon and converts his results to binary bit values in the same way that Alice did. Now Alice and Bob openly contact each other to compare the orientations they chose, but not their actual bit values. Suppose five photons were sent. If Alice and Bob selected different orientations on photons 2 and 5, then Bob had a



The quantum key distribution hardware engineered at Los Alamos sits beside a thoroughly nonquantum key, shown for scale.

50/50 chance of matching Alice for each of those two bits. In this way, quantum randomness prohibits any meaningful connection between Alice's bits and Bob's bits, so both people cross out bits 2 and 5. They keep the remaining bits—1, 3, and 4—as their quantum key. Without having to directly compare these bit values, both people know that the values are the same (if Alice has 010 then Bob must also have 010) because Bob measured the polarizations with respect to the same orientation that Alice chose.

If spies intercept the key transmission, they won't know which bits to throw away unless they also intercept the measurement orientation comparison between Alice and Bob. But assuming they do that, their own measurements will have changed the photons' polarizations, so Bob will end up with different results, like 110. Now Alice and Bob can compare their keys without revealing them. For example, they might add the digits and compare those sums. Alice gets 1 (that's  $0+1+0$ ) and Bob gets 2 (that's  $1+1+0$ ). Because they disagree, they conclude that someone must be spying on them and throw the key away. Since they haven't sent the actual message yet, the spies never see any sensitive information. (In a real application, the original transmission would be much longer than five photons, and the key would be much longer than three digits. In addition, the sender and receiver can perform verifications much more sophisticated than simply adding all the digits.)



The QKarD uses a dock with a fiber-optic connection to produce quantum keys by transmitting polarized photons. The card itself can then store those keys securely and portably, so that a key is ready whenever or wherever the next secure communication is needed. This picture is just a concept, not a prototype.

All of this can be accomplished with communications networks that are already in place. All that is required is an optical transmission medium for the polarized photons—either open-air (like satellite to ground) or fiber-optic cables. In the event that an eavesdropper tampers with their polarized photons, Alice and Bob could agree to switch to a different, untapped connection, such as a different fiber-optic path between them. Moreover, Alice and Bob don't need any training; an electronic device at each end can do all the polarization measurements and the bit comparisons automatically.

Bear in mind, however, that quantum cryptography only protects transmissions. Alice and Bob can still be tricked or coerced, and their equipment can still be hacked or stolen. So conventional safeguards like passwords are still important. What Los Alamos's new technology ensures is that secret keys can no longer be intercepted during transmission without being detected.

### Wireless Wonder

The new Los Alamos hardware (shown on page 9) employs a laser together with variable-direction polarization components to establish a secret key between sender and receiver. The key could be used to encrypt (and later decrypt) a message sent by any means—over the Internet, phone, satellite, or even carrier pigeon. That is, only the key generation requires a quantum channel—photons, polarizations, and fiber optics. Once the key is established, the

encrypted information can be sent by any available means, including wireless.

Nordholt, Hughes, and their team have invented, as a proof of concept, a new technology they call QKarD. (The capitalized letters stand for quantum key distribution.) QKarD is a small, handheld smart card that can supply quantum keys for a variety of uses. When the card is docked in its charging station with a fiber-optic network, it automatically establishes the next thousand or so keys it will need and stores them in secure memory. The card can then be undocked and carried around by its owner.

Because quantum keys must be established between a sender and receiver, and the QKarD doesn't know who the next receiver will be while it is docked, an external server is needed to manage all transmissions. This server would reside with a trusted private or government agency. A docked QKarD establishes keys between itself and this agency.

When the QKarD owner wants to send a secure transmission—for example, to transmit her credit card number to an online bookstore—she connects the QKarD to a computer or other mobile device. Her credit card number is encrypted with the next available quantum key on the QKarD, and the transmission is sent to the bookstore. The bookstore notifies the trusted agency that the transmission occurred but does not share the encrypted credit card number with that agency.

The bookstore uses QKarD technology just as the consumer does, so it has its own quantum keys already established with the same trusted agency. At the time of purchase, the agency tells the online bookstore which bits to flip (from 0 to 1 or vice versa) to transform the bookstore's next available quantum key into the same quantum key from the buyer's QKarD. In this way, a common quantum key is established between the buyer and seller with the help of the trusted agency, but without the buyer needing a fiber-optic connection at the time of the purchase.

This QKarD system is completely mobile, apart from the need to be docked from time to time to acquire quantum keys while charging. Therefore it could serve all wireless transmissions—laptop computing, cell phone calls, e-commerce, and so forth. For example, QKarD technology could be integrated into a future generation of smart phones. Every transmission from every app would be secure.





## Scrambled Bits

The Los Alamos team has also created a second prototype system for enhanced security and privacy. Known as quantum enabled security (QES), it is both a device and a communications protocol. It uses QKarD keys to hide data transmissions from potential eavesdroppers.

Some networks that provide fiber-optic lines to homes, for example, employ 32 wavelengths simultaneously to 32 homes. The receiving electronics system in each home is programmed to pay attention to just one particular wavelength and ignore the other 31. So everyone's data also goes into 31 other homes. But the QES system uses a secure quantum key to obscure every message in both wavelength and time. Messages are scrambled with different bits hopping among different wavelengths at different moments. Only the authorized receiver's hardware, which has the key, knows how to unscramble the hopping and pay attention to only the right wavelengths at the right moments, to pick up every 0 and 1. This is known as physical-layer security—the most robust kind—because one needs to physically select the right bits to acquire the hidden, encrypted message. While other security schemes allow eavesdroppers to record encrypted messages, eavesdroppers on a QES system can't even identify which bits contain the encrypted message.

The QES technology is limited by the distance a single photon can travel through fiber-optic cables without its polarization degrading. That distance is at least 140 kilometers (87 miles), meaning that hardware needs to be placed at stations no more than 140 kilometers apart. (It is possible to break a 280-kilometer transmission, for example, into two 140-kilometer transmissions that each have their own key.) Until such hardware is set up throughout the country or the world, QES is ideal for more localized security, such as between buildings on the same campus, industrial site, neighborhood, or metropolitan center. It is also well suited for securing information within isolated entities, such as U.S. embassies abroad or national security facilities like Los Alamos National Laboratory.

Perhaps the greatest benefit of the new QKarD and QES technologies is that they are future proof. New mathematical techniques and new computers—even future quantum computers—will not be able to crack their codes because of the probabilistic manner in which they establish quantum keys between sender and receiver. Unlike a classical key that is generated by a mathematical algorithm, a quantum key is naturally random and therefore cannot be calculated.

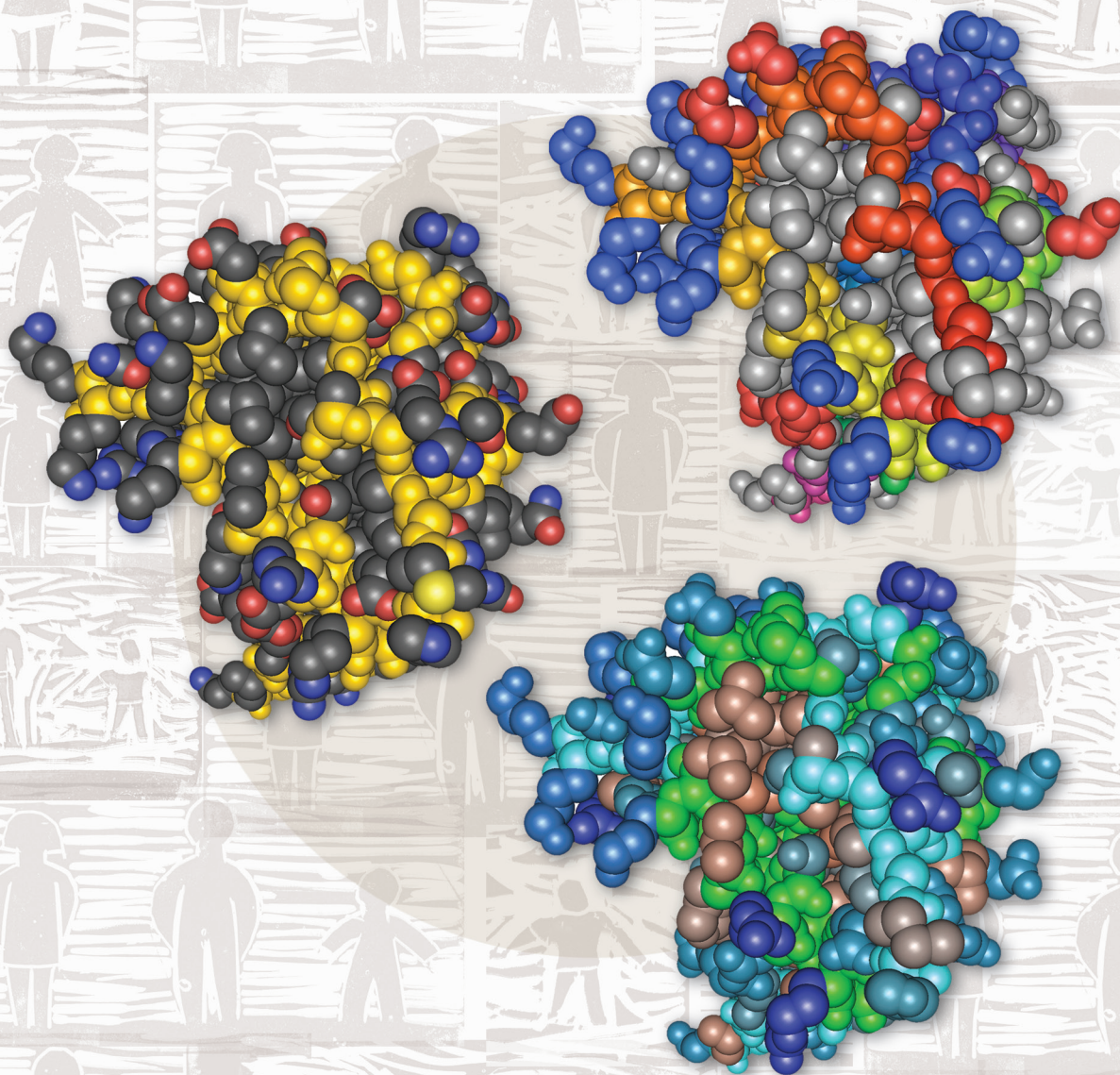
Both QKarD and QES have been offered for license, with some of the biggest telecommunications companies and others expressing interest. And no wonder: they'll be able to offer their clients complete protection, security, and privacy, which will be forever guaranteed by the laws of physics. ♦ **LDRD**

— Craig Tyler

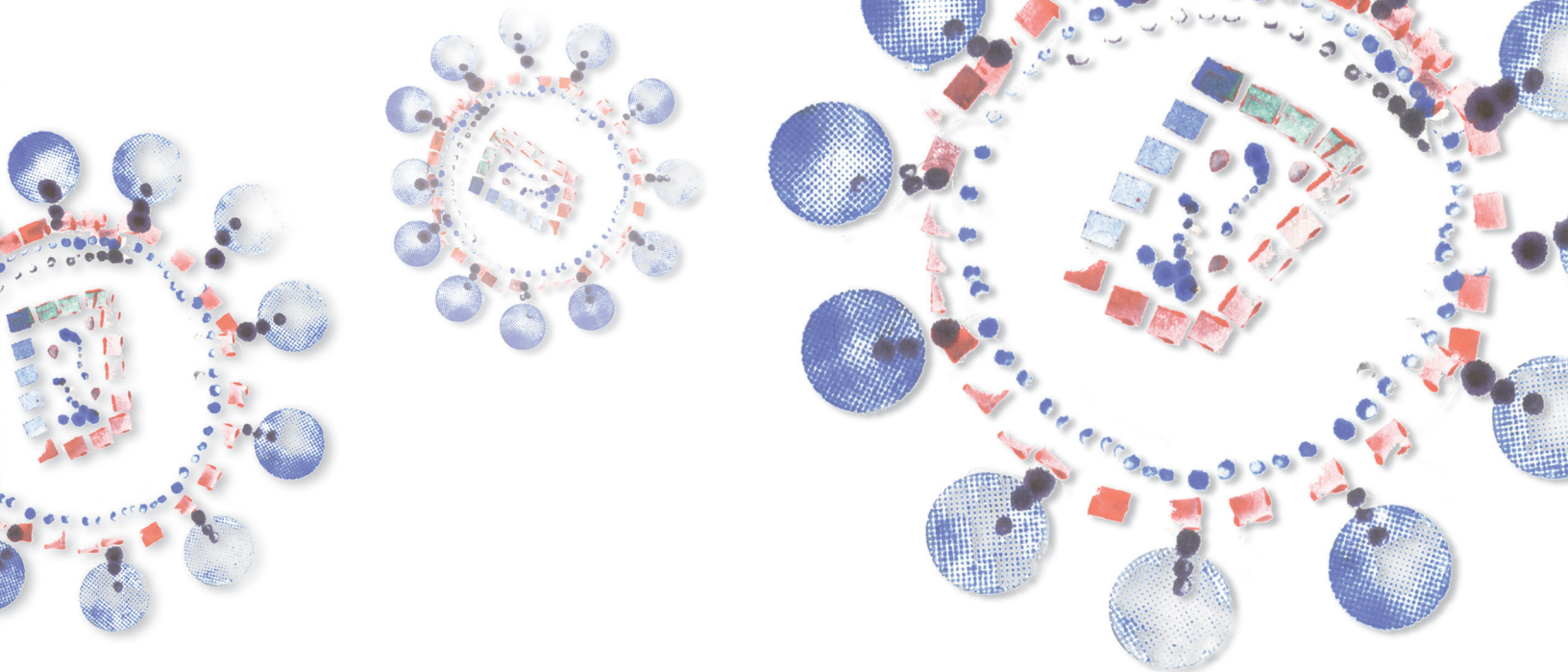


# A Chance to Save Lives

Mosaic proteins hold the promise of becoming the first viable vaccine to protect people from the virus that causes AIDS.







**Bette Korber** of the Los Alamos Theoretical Biology and Biophysics group types a command on her computer and brings up a graph replete with more than a dozen sets of vertical lines.

“This is what caught everyone’s attention,” she says softly, pointing to a set of multicolored lines strikingly longer than the others. “It shows that in rhesus monkeys, at least, the artificial mosaic proteins elicit a significantly broader immune response than natural proteins. As a vaccine they should offer greater protection against rapidly evolving viruses like HIV.”

The human immunodeficiency virus, HIV, causes a weakening of the body’s immune system. It infects—and cripples—the helper T cells (CD4<sup>+</sup> cells) that are critical to a healthy immune response, and though people can live with HIV infection for years without treatment, at some point the disease progresses to acquired immune deficiency syndrome, or AIDS, the 100 percent fatal end stage that is characterized by an immune system too compromised to stave off various opportunistic infections. HIV is also known to act synergistically with other diseases, such as tuberculosis, and may be linked to the 4-fold increase in tuberculosis in countries where HIV is rampant.

In the thirty-some years since HIV was identified, the virus has wreaked a global pandemic of fearsome proportions: 27 million dead, 33 million infected, and rates of 3 million infections and 2 million deaths per year. Put another way, if the virus had plagued only the United States, more people than currently live in Texas and New Mexico would have already died from AIDS; everyone in the coastal states of New Jersey, Maryland, Delaware, Virginia, North Carolina, and the District of Columbia would be living with HIV; all of Chicago would likely become infected this year; and the nation should prepare to bury everyone in Indianapolis, Denver, and Albuquerque by year’s end. So far, the health-research community has been unable to create a widely applicable vaccine that could curtail the spread of the virus. There are many reasons for that, the main one being that HIV is one of nature’s great quick-change artists—the virus mutates so fast that some version always emerges that goes unrecognized by a person’s immune system.

But there’s newfound hope for containing or reversing the spread of HIV and eradicating AIDS. Korber’s eclectic team of immunologists, biologists, physicists, and computer programmers developed the mosaic proteins—so named because they are constructed from many small protein pieces—specifically to help the immune system fend off HIV. They just might have succeeded.

Bette Korber



From the initial awareness of HIV/AIDS in 1981, about 60 million people have been infected with HIV and more than 27 million have died. The AIDS Memorial Quilt is a poignant reminder of the toll taken by the pandemic. It consists today of more than 44,000 individual 3-by-6-foot panels sewn together in sections, the vast majority of which commemorate the life of someone who has died of AIDS. The photo shows the AIDS Memorial Quilt in Washington, DC, 1987.

SOURCE [HTTP://WWW.PASSPORTMAGAZINE.COM/BLOG/ARCHIVES/1633-NATIONAL-GAY-MENS-HIVAIDS-AWARENESS-DAY.HTML](http://www.passportmagazine.com/blog/archives/1633-national-gay-mens-hivaids-awareness-day.html)



An immunologist and evolutionary biologist of international distinction, Korber is quick to mention that research on a mosaic-protein vaccine is still in its early stages, that it isn't known yet whether the vaccine will be effective in humans. Phase I trials, led by Barton Haynes of Duke University, have barely gotten underway; they will check the safety of the proposed vaccine's components and see the efficacy of the immune response in humans. If the results are promising, a vaccine comprised of three or four mosaic proteins will be tested in a large-scale human trial to assess its level of protection.

"This has been my life's work," says Korber. "While there's much more to do, many indicators suggest we're on the right track."

## Immune Response

That a vaccine can help protect us from specific disease-causing bacteria, viruses, or other organisms (pathogens) follows from how the body's defenses work. Whenever a pathogen is detected, some immune cells mature and become activated to fight the microbe. But the large-scale maturation of cells takes time, so the initial immune response to an unknown pathogen tends to be relatively slow and weak. We're sick until the response becomes strong enough to clear the infection.

The silver lining, however, is that after that first encounter, a small cadre of activated cells remain as long-term "memory" cells. Subsequent encounters with the pathogen send a call to action to the memory cells, which then expedite the production of cells and proteins that specifically target the invader.

The vaccine's job is to initiate a strong immune response and create a strong immunologic memory against the pathogen without making a person ill. It does so by introducing into the body a nonpathogenic surrogate, typically a weakened or dead form of the pathogen itself, or a part of the pathogen, such as some of its DNA or proteins.

To date, every successful vaccine (against typhoid,

polio, small pox, measles, and others) has stimulated an antibody-based immune response. Once a pathogen has been recognized and targeted, small proteins (antibodies) are created that stick selectively to any pathogens found circulating through the blood or lymph systems, inhibiting their ability to infect cells or marking them for elimination by "cellular hit men." It's no surprise, then, that many attempts at an HIV vaccine have been and still are antibody-based. So far, those vaccines have failed to demonstrate significant, long-term protection against HIV.

Korber's mosaic vaccine is different. It is designed to stimulate primarily a cellular immune response, which targets and eliminates infected cells instead of mobile pathogens. The strategy revolves around the short protein segments called T-cell epitopes that a cell uses to talk to the immune system.

Proteins are the miraculous do-everything molecules of the cell, and every cell in the body produces and destroys them as necessary. Unneeded or damaged proteins are chopped into small pieces only a few to a dozen amino acids long. (Amino acids are small molecules that link together to form a protein.) Pieces that are 8–12 amino acids long can be captured and held, like a hotdog in a bun, by a large protein known as the major histocompatibility complex (MHC). This protein will ferry the T-cell epitope to the cell's outer surface, where immune system cells can examine it. The principal examiners are white blood cells known as killer T cells (CD8<sup>+</sup> cells), which continually roam the body looking for cancerous or infected cells.

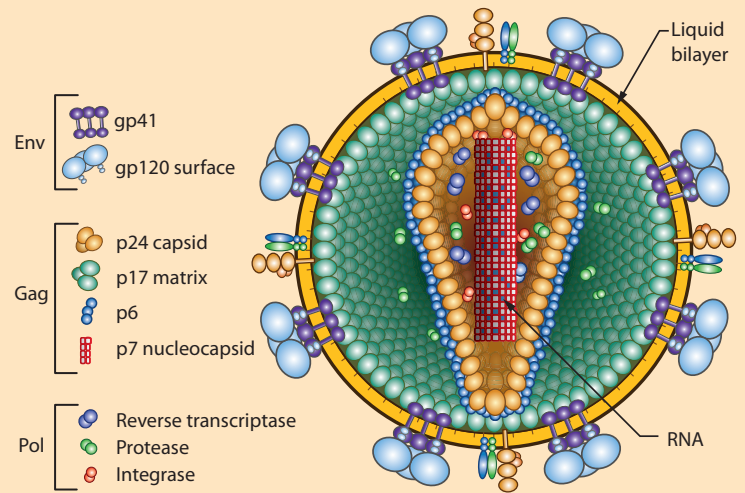
When a pathogen, say a virus, invades a cell, it forces its host to make the virus's proteins. These also get chopped up into T-cell epitopes and displayed on the cell's surface. A mature killer T cell, set to eliminate a particular type of pathogen, inspects the segment using highly specialized surface proteins that only bind to the pathogen's T-cell epitopes. (See "Immune System Activation" on page 16.) If binding occurs—condemning evidence that the targeted pathogen has invaded—the killer T cell attacks and kills the infected cell.



# HIV

HIV is a roughly spherical retrovirus approximately 120 nanometers in diameter. (About 25 million would fit on the head of a pin.) Retroviruses use RNA as their genetic material, carrying with them a protein called reverse transcriptase (RT) to copy their RNA into DNA. Another protein, called integrase, then integrates the viral DNA into the cell's genome, and the cell begins to make the proteins needed to produce a functioning virus. But the RT does sloppy work, so the DNA copies of HIV's genome are always a little different than the RNA originals. This is one of the root causes of HIV's diversity.

HIV has nine genes, three of which (*gag*, *pol*, and *env*) encode for polyproteins that get broken into smaller proteins. The *Gag* proteins make up the physical infrastructure of the virus; for example, *Gag*-p24 and *Gag*-p6 proteins protect the virus's RNA/protein core. The *Pol* proteins provide enzymes needed by the virus to reproduce, while the *Env* proteins stud the virus's surface



and are used to enter a host cell. The remaining six genes encode for proteins that enhance expression of the virus's genes and inhibit the expression of the cell's genes.

ADAPTED FROM AN IMAGE PROVIDED BY LOU HENDERSON, HENDERSL@NCICRF.GOV.

The idea behind the mosaic HIV protein is that while it mimics the overall size and shape of a natural HIV protein, it's constructed from the potential T-cell epitopes that are commonly found among the different natural HIV variants in circulation about the world. Regardless of how it is chopped up, a mosaic protein will produce those recurrent T-cell epitopes and, ideally, broad immunologic memory against the most prevalent HIV variants.

## Virus of a Thousand Faces

The exotic mosaic protein is needed because of HIV's extraordinary diversity. By way of explanation, Korber brings another graphic up on her computer monitor, this one of a phylogenetic tree of the main (M) group of HIV variants. These are the viruses responsible for the global pandemic.

With nine distinct subdivisions, or clades, each representing in some cases thousands of genetically distinguishable viruses, the M-group is visual evidence of HIV's diversity. The Los Alamos HIV sequence database, a global resource to assist in HIV research and analysis that is run by Korber and colleagues Carla Kuiken, Karina Yusim, and Thomas Leitner, contains more than 2600 complete HIV genomes, and well over 330,000 gene sequences. (A gene is a segment of DNA that is the blueprint for a particular protein; the protein itself is a sequence of amino acids, and different versions of a gene have different amino acid sequences.

Genome refers to all of an organism's genetic material—genes plus any non-protein-producing DNA segments.)

The driving force behind HIV's diversity is the inaccurate copying of its genome; the instructions for producing newly made viruses are almost always a little different than the original. If one were to isolate the same HIV protein from two different viruses and compare them side by side, up to 35% of the amino acids would be different. This diversity lands smack on the immune system's Achilles heel, namely that a mature killer T cell will only bind to identical, or nearly identical, T-cell epitopes (likewise for antibodies). The natural variation of HIV proteins and the resulting variation within the epitopes means that many HIV variants will go unrecognized by the immune response.

## A Beautiful Idea

It was 1994 when Korber began thinking that the extraordinary diversity of the virus would likely prevent conventional vaccines from working. She envisioned creating an artificial strain of the virus, with a genome that would place it at the center of the M-group's family tree. That central virus would be genetically closer to any other virus in the tree than viruses from different clades are to each other. Activating the immune system to fend off the central virus might allow it to fend off any HIV variant within the M-group. That result might also be achieved

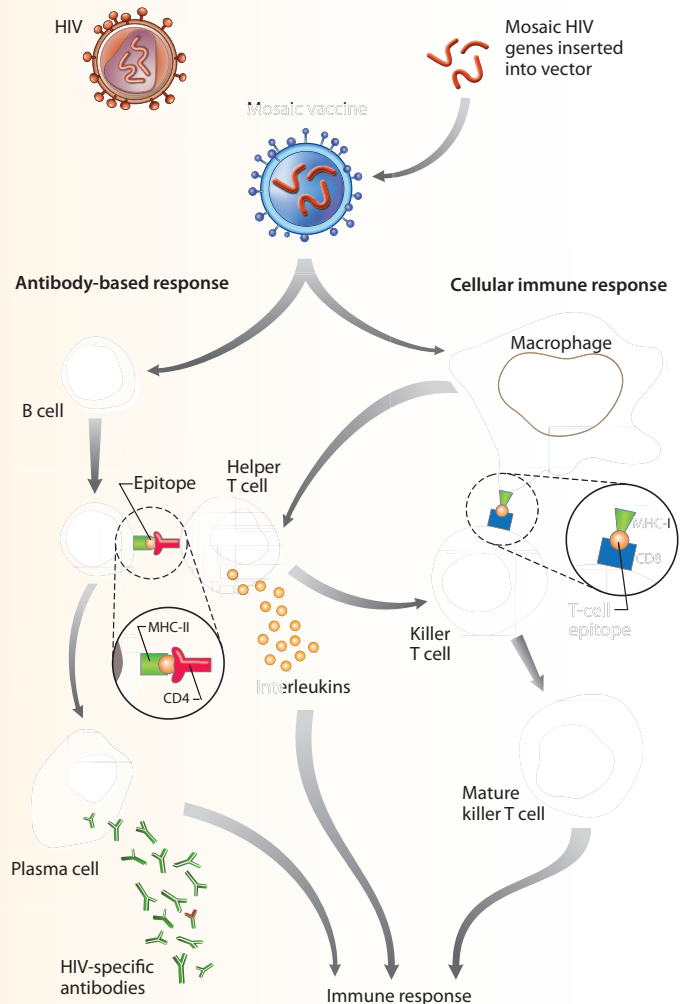
## Immune System Activation

Our immune system has evolved to fight off nearly any pathogen, but it must be activated before it does battle. The illustration summarizes the activation of the two main response modes.

Starting with the cellular immune response, a pathogen in the body is ingested by an antigen-presenting cell (APC), such as a macrophage. It's broken apart inside the APC, and a protein fragment (T-cell epitope) is presented at the cell surface in an MHC-I protein complex. A killer T cell will interrogate the epitope using its CD8 receptor, which binds only to a particular foreign epitope from a particular pathogen. If binding occurs, then small signaling molecules (interleukins) secreted from a mature helper T cell cause the killer T cell to mature. This activated killer T cell then roams the body looking for and killing infected cells.

An APC will also display epitopes in an MHC-II complex, which is examined by the CD4 receptor of a helper T cell (not shown). If binding occurs, the APC will secrete interleukins that make the helper T cell mature.

The mature helper T cell is also needed to activate B cells, which are central to the antibody-based response. The B cell carries a unique receptor on its surface that only binds to specific pieces of a pathogen. Binding causes the B cell to engulf and break the pathogen apart, followed by the display of an epitope in a MHC-II complex on the cell's surface. If a mature helper T cell binds to the epitope, it releases signaling proteins (interleukins) that transform the B cell into an antibody factory. The antibodies will circulate through the body and glom onto their targeted pathogen. This inhibits the pathogen's



function and tells a macrophage or other predatory cell to engulf and destroy the intruder.

Both responses require mature helper T cells, the cell that HIV overwhelmingly infects. In targeting and eliminating these cells, the immune system causes its own breakdown, the devastating last stage of which is called AIDS.

simply by immunizing a person with a central gene, either a resurrected ancestral gene or a consensus gene, which is essentially the average gene from a large number of HIV variants.

Korber's colleague, Feng Gao at the University of Alabama, was the first to test the central-gene idea in the lab. Gao's promising initial results were seconded after Haynes at Duke and Norman Letvin at Harvard proved that a

centralized vaccine could induce a monkey's immune system to recognize multiple viral variants. This was the result Korber had hoped for, that a centralized vaccine could prepare the immune system to cope with a rapidly mutating virus.

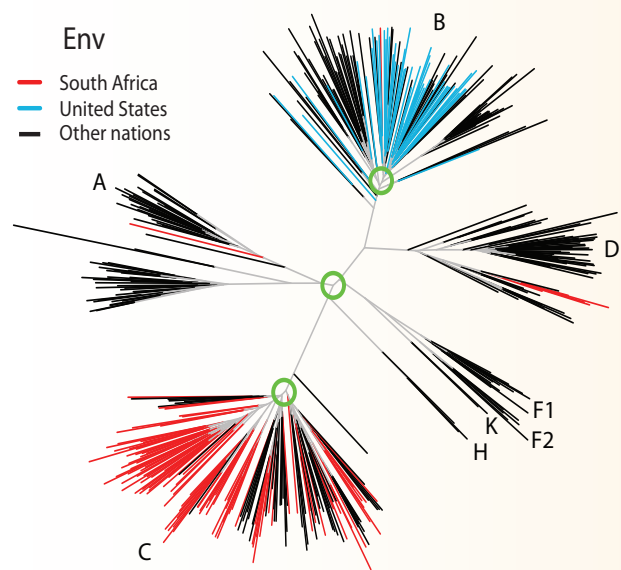
The favorable early results encouraged Korber to consider a vaccine that would transport several central genes into a cell—leading to the production of central proteins and a set of T-cell epitopes—and how one might optimize the set



## HIV Diversity

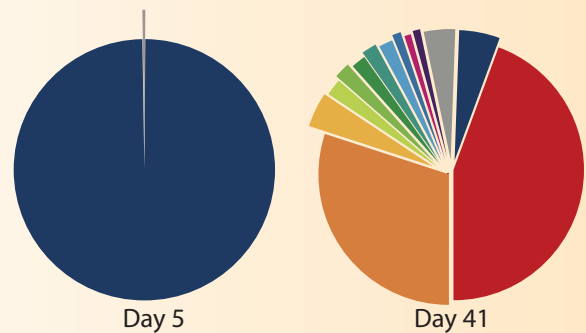
The genetic diversity of HIV is revealed by the tree of the main (M) group (below), which breaks into nine clades (labeled A–K) of closely related viruses. The tip of each line represents one of the hundreds of variations of the *env* gene, each belonging to a different viral variant. The United States epidemic is driven by B-clade viruses (blue lines); the one in South Africa is driven by those in the C-clade (red lines).

A line connects two gene sequences, with the length of the line related to the number of mutations needed to convert one sequence to the other (the genetic distance). The green circles at the B- and C-clades indicate nodal ancestral



genes. In general, the genetic distance between a gene and its nodal ancestor is shorter than the distance between any two genes in the clade, so a vaccine made with the ancestral gene has a chance to immunize a person against all viruses in the clade. The middle circle represents the ancestral gene for the entire M-group. A central vaccine would use one, or all three, of the ancestral genes.

One consequence of HIV's flexible genome is that it is able to avoid a person's immune system indefinitely. The pie charts (below) show the viral diversity within a newly infected individual. After five days, this person had only two variants (blue and gray), with one (blue) completely dominating the viral load. Thirty-six days later, the immune system had successfully targeted that virus, but many new variants (colors) were generated that were not targeted by the immune response. Korber and collaborators have shown that HIV can evolve away from an immune response in as little as three weeks.



to maximize the immune coverage. She was funded by a Los Alamos directed research project to form a team that would develop computational methods and design a small number of artificial proteins. The team began referring to their work as the mosaic vaccine problem.

"It's relatively easy to assemble several 'generic' versions of the protein, using only the most common forms of the possible epitopes," says Will Fischer, a scientist on the mosaic team. "But because epitopes can overlap, assembling the proteins turns out to be a hard optimization problem. The choice of which 'version' to use isn't always obvious. Plus, joining the pieces has to be done carefully, to avoid creating spurious epitopes at the junctions that do not exist in nature."

The mosaic vaccine problem was tackled by a team

that included Fischer, Simon Perkins (currently at Google), Tanmoy Bhattacharya, and James Theiler. Somewhat appropriately, their computer-based solution relied on genetic algorithms.

### A Mosaic Set

Genetic algorithms are a class of methods often used to solve problems that are too hard, or too expensive, to solve analytically. The methods are modeled after evolution: candidate solutions (a population) are evaluated and selected based on a set of criteria (evolutionary pressures), then randomized in some way (sex), to produce new solutions (offspring). The steps are repeated until an optimal solution emerges.

## Building a Mosaic Sentence

A set of mosaic proteins can be a better choice for a vaccine than a similar set of natural proteins, a concept we can illustrate by linking words together to form mosaic sentences.

A mosaic sentence is built using only the words found within an initial set of “natural” sentences, just as a mosaic protein is built from the small protein segments (epitopes) obtained by chopping up a set of natural proteins. Our initial set contains 10 sentences, and just for fun, each is a pangram (a sentence containing all 26 letters of the alphabet) derived from the ancestral pangram: *The quick brown fox jumps over the lazy dog*. The initial set is shown at right. There are 95 words in the set, but only 26 unique ones, as some words (such as “quick”) appear many times. We define the coverage as the number of unique words in a set of sentences divided by the number of unique words in the initial set.

The goal is to construct a set of mosaic sentences that maximizes the coverage, where each mosaic is a pangram with words in a certain order (no dogs jumping over foxes), and each only uses words that appear more than once in the initial set. These rules are simplified versions of the criteria used to construct mosaic proteins. A mosaic protein should only contain epitopes found in the viruses one is trying to immunize against, it must resemble a natural protein to ensure a cell will process it properly, and the epitopes should be common to many viruses (not rare epitopes). The coverage is analogous to the breadth of the theoretical immune response.

A nearly optimal set of two mosaic sentences is shown, and the graph shows that it has much greater coverage (blue dot) compared to any set of two sentences from the

initial set (orange dots). In this example, the 10 natural pangrams were deliberately constructed to lead to an impressively large difference. For HIV, a set of mosaic proteins has been found that should initiate a broader immune response than a similar set of natural proteins.

\*DETAILED INFORMATION ABOUT MOSAIC PROTEINS CAN BE FOUND IN FISCHER, W., ET AL., NATURE MEDICINE 13(1):100, 2007.

Ancestral pangram:

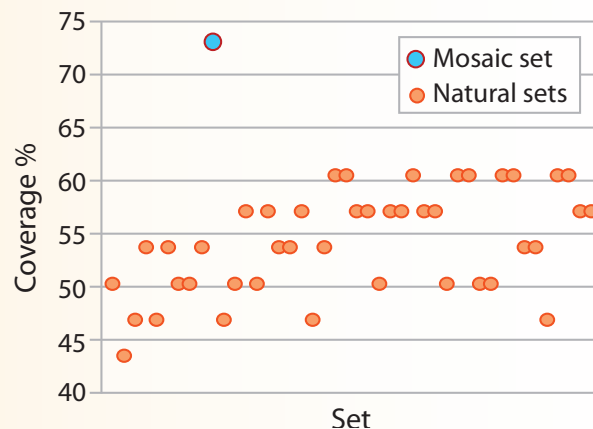
The quick brown fox jumps over the lazy dog

Set of natural pangrams, aligned. Number of unique words = 26.

|      |        |          |       |        |      |       |       |       |      |
|------|--------|----------|-------|--------|------|-------|-------|-------|------|
| The  | quick  | brown    | fox   | jumped | over | the   |       | lazy  | dogs |
| The  | quick  | brown    | fox   | jumped | over | these |       | lazy  | dogs |
| Then | quick  | brown    | foxes | jumped | over | this  |       | lazy  | dog  |
| That | quick  | brownish | fox   | jumped | over | this  |       | lazy  | dog  |
| The  | quick  | brown    | ox    | jumps  | over | his   | fat   | lazy  | dog  |
| The  | quick  | brownish | ox    | jumps  | over | this  | fat   | lazy  | dog  |
| That | quirky | brown    | ox    | jumped | over | this  | flat  | crazy | dog  |
| The  | quirky | brown    | ox    | jumped | over | his   | flaky | crazy | dog  |
| The  | quirky | town     | fox   | jumps  | over | this  | black | crazy | dog  |
| That | queazy | town     | fox   | jumps  | over | his   | black |       | dog  |

Set of mosaic pangrams:

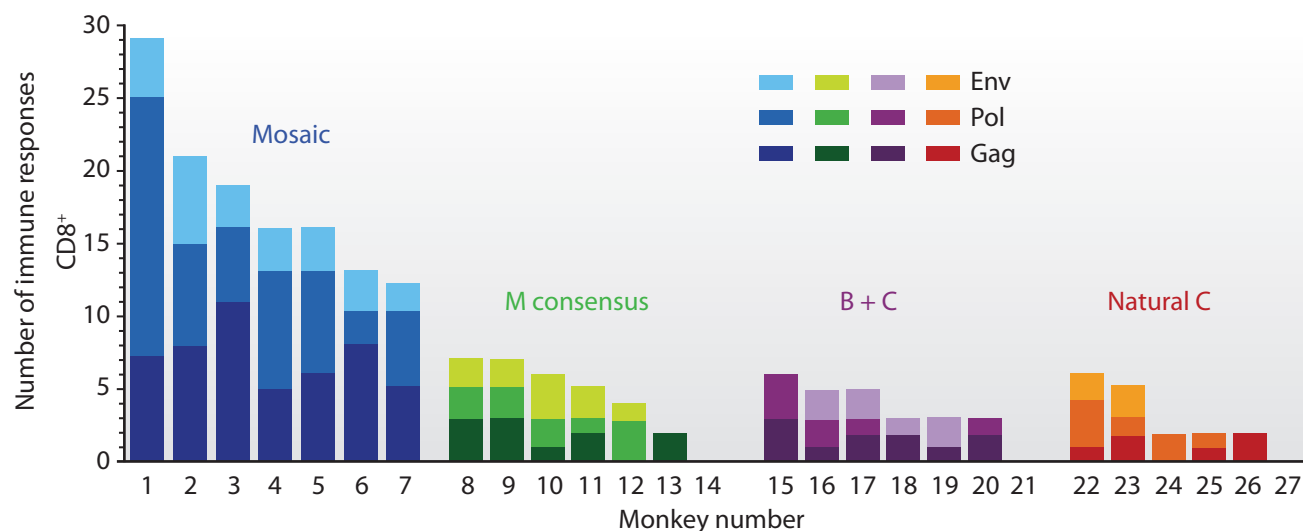
|      |        |       |     |        |      |      |       |       |      |
|------|--------|-------|-----|--------|------|------|-------|-------|------|
| The  | quick  | brown | ox  | jumped | over | this | fat   | lazy  | dog  |
| That | quirky | town  | fox | jumps  | over | his  | black | crazy | dogs |



Perkins designed a genetic algorithm that elegantly generates near-optimal results. Candidate proteins are generated in the computer by recombining two versions of the same natural protein (interchanging arbitrary but equal-length pieces), each plucked at random from among thousands stored in a database. The recombined proteins are evaluated to see, for example, if they contain unnatural

sequences, and then scored according to how many common epitopes they contain. The top-scoring proteins are grouped into a set, which is similarly scored. The proteins are then returned to the database, and at speeds that only a computer could achieve, the process repeated until a set of proteins is generated that will produce the largest number of frequently encountered HIV T-cell epitopes.





In a study led by Dan Barouch of Harvard, 27 rhesus monkeys were immunized with one of four sets of HIV *Gag*, *Pol*, and *Env* antigens, the antigens being either mosaic (blue), M-group consensus (green), B-clade + C-clade (purple), or optimal natural C-clade proteins (orange). The figure shows the number of antigen-specific killer-T-cell (CD8<sup>+</sup>) responses for each monkey. The total response to the mosaic proteins was almost four times greater than it was to either consensus or natural proteins.

FIGURE MODIFIED WITH PERMISSION FROM *NATURE MEDICINE* 16, 319-323 (21 FEBRUARY 2010). SEE ALSO *NATURE MEDICINE* 16, 324-328 (21 FEBRUARY 2010).

Korber recalls that initially, the suggestion that an artificial, designed-on-a-computer protein might be useful for a vaccine was too radical for the HIV research community. “In 1995,” she says, “people were unwilling to even test the concept, as they felt an artificial protein would never fold up correctly or be stable and elicit good immune responses. Feng Gao and Beatrice Hahn, his mentor at the time, changed that perception with those first experiments. Mosaic vaccines were another stretch, and a priori were deemed so far out of reach that several grants were turned down before we got funded to do the theory for this work.”

### Hope for a Vaccine

Aside from the Haynes studies, other Phase I studies with mosaics are going forward under the leadership of Dan Barouch (at Harvard) and Nelson Michael (in the U.S. Army). Those studies will test different strategies for delivering a mosaic-protein set.

Other intriguing HIV vaccine strategies are being explored by other groups, including vaccines designed to elicit improved antibody responses and vaccines that carry the most conserved regions of HIV. Ultimately, it may take a combination of the best approaches to create an effective HIV vaccine.

Mosaic vaccines may prove useful against other rapidly evolving viruses. Says Carla Kuiken, head of the Los Alamos Hepatitis C (HCV) database, “We adapted the algorithm

developed by Bette’s team to HCV. The main issue we faced was the uneven sampling—some HCV clades have only a few published sequences. But we were able to construct some HCV mosaics that look very promising. The designs are also being tested by Barouch at Harvard.”

A collaboration between Korber’s mosaic team and Los Alamos biophysicist Paul Fenimore resulted in a set of mosaic vaccines against the filoviruses (which include Ebola virus). The vaccines are being tested in collaboration with John Dye, an infectious disease expert in the U.S. Army. If these designs continue to do well, the mosaic method can be applied to a long list of other variable viruses against which current vaccines do not work well.

While optimistic about the results of these studies, Korber has little sense of satisfaction. “This virus destroys lives,” she says. “There’s no cure for it, and without constant medication, it will eventually kill you. Preventing HIV infections through a vaccine is likely to be the best way to curb its impact, if we can find a way to reach that goal.”

And if a way is found to not just curb, but eradicate the virus altogether? Korber won’t miss it. ❖ **LDRD**

— Jay Schecker

# GLOBAL SECURITY

## The Growing Challenge

A dialogue with the Laboratory's principal associate director for global security and the recent acting director of the Office of Counterintelligence



*William (Will) Rees has led the Principal Associate Directorate for Global Security (PADGS) since the organization was created in 2009. He and Terry Hawkins, then acting director of the Office of Counterintelligence, agreed to talk with 1663 about the Laboratory's global-security mission and operations. Global security is regarded internally and externally as a core mission of the Laboratory. The Office of Counterintelligence falls within the PADGS organization.*

*Rees has roots in academia. For over a decade he was a full professor and director of the Molecular Design Institute at the Georgia Institute of Technology. Rees came to the Laboratory from the Science and Technology Policy Institute in Washington, DC, where he is a fellow. Prior to that, Rees was deputy under secretary of defense for laboratories and basic sciences in the Department of Defense. In January, Rees was elected a fellow of the American Association for the Advancement of Science.*

*Hawkins, a Laboratory senior fellow, joined the Laboratory in 1988 after a career in the U.S. Air Force. He served as the division leader for both the International Technology Division and the Nonproliferation and International Security Division. Hawkins became acting director of the Office of Counterintelligence in July 2010 and is now a senior scientist for PADGS.*

**1663:** What is the significance of the Laboratory creating a Principal Associate Directorate for Global Security?

**Rees:** As a Department of Energy (DOE), National Nuclear Security Administration national security laboratory, we have a long, proud history of devoting science of the highest caliber to the most pressing issues of national security. The core mission of the Laboratory has always been and will always be to help ensure the safety, security, and reliability of the nation's nuclear weapons stockpile. Closely coupled to our core mission is our role in helping to ensure our national security in a broader sense, which includes, for example, nuclear nonproliferation. This focus on nonproliferation is reflected in the fact that the PADGS used to be called the Threat Reduction Directorate, and before that the Nonproliferation and International Security Division.

**Hawkins:** Nonproliferation is a key mission of the Lab that has existed since the days of the Manhattan Project. We had to assess the nuclear threat posed by both Germany and Japan. What generally isn't known is that the Japanese arguably had a better understanding of nuclear weapons physics than their Nazi allies.



Following World War II, the importance of nonproliferation grew tremendously as more nations joined or attempted to join the nuclear weapons club. There were successes; for example, Switzerland, Sweden, and West Germany each stopped their nascent nuclear weapon programs, and in 1989, South Africa dismantled its nuclear weapons and placed their fissile material under international safeguards. Los Alamos played a key role in this important South African outcome.

With the end of the Cold War, the international security environment dramatically changed again. First, Russia agreed to convert a large fraction of its nuclear weapon material for use in peaceful nuclear energy programs. Today, one out of ten light bulbs in the U.S. is powered by converted nuclear weapon material from Russia. Other bright spots followed, such as the 2003 decision by Libya to halt and dismantle its program. Again, Los Alamos played significant roles in these, and in other, successes in nonproliferation.



Will Rees (left) and Terry Hawkins.

Despite our successes, the determined quest for nuclear weapons continues, often by states with societal instabilities and with direct financial and philosophical ties to international terrorist organizations. In addition, this quest was encouraged and enabled by the infamous A. Q. Khan of Pakistan, who operated a network for shoppers seeking technology for nuclear materials production and nuclear weapon designs and manufacturing—until his illicit activities were shut down. By establishing a cooperative international computer network for the DOE, Los Alamos has played a major role in detecting illicit activities, such as those perpetrated by the Khan

network, and preventing the illicit international trade in commodities associated with nuclear material and weapons.

*U.S. officials believe there is a high probability of an attack using a WME in the near future, somewhere in the world. No matter where it occurs, no matter if it's perpetrated by a terrorist organization or a failed state unable to secure its WMEs, this event will have a major impact on global security, and by extension, our national security.*

**Rees:** So when the international security environment changes, our national security imperatives must change in concert. As a result of these new realities, we are as concerned about a truck-delivered nuclear weapon as we were concerned about nuclear weapons delivered by intercontinental ballistic missiles (ICBMs) in the Cold War period. To state the problem another way, there are far more trucks to watch than ICBMs. This is why, for the first time, the Nuclear Posture Review places the goal of preventing nuclear proliferation and nuclear terrorism at the top of the nation's nuclear agenda. President Obama has a very bold international nonproliferation agenda. The president wants, over the next few years, the fissile material in the world to be controlled. That's a challenging goal—but a goal that must be achieved. It simply is not sufficient to have controlled all but a few weapon's worth of highly enriched uranium or plutonium.

**1663:** What makes it so challenging?

**Hawkins:** First of all, we do have the ability to monitor fissile materials where they are being stored or used under

international safeguards. The cadre of International Atomic Energy Agency (IAEA) inspectors plays a crucial role in safeguarding this material. And where were all the IAEA inspectors you see trotting all over the globe trained? They were trained here at Los Alamos. Moreover, these inspectors are using safeguards technologies that were largely invented here at the Lab. The problem isn't that we don't have the people, skills, and technology. As Will said, it's that significant quantities of fissile material are still unaccounted for. In addition, there are known caches that might be subject to theft, diversion, or sale to the highest bidder. Dealing with these latter threats is the challenge we, and the world, face everyday.

**Rees:** We say that it takes an established nuclear weapons lab to find a hidden nuclear weapons lab. That is part of our nonproliferation role, also. Part of our skill set is focused on finding nuclear weapons labs all over the globe no matter where they're trying to hide. In like fashion, if Los Alamos can design and build a nuclear weapon then we certainly have the requisite knowledge to disarm and dismantle a stolen or improvised nuclear weapon. So threat response is part of our global-security mission: our National Emergency Search Team, the NEST—with our equipment already palletized, our pagers always on—would be on a plane heading into the threat if, heaven forbid, a threat materialized.

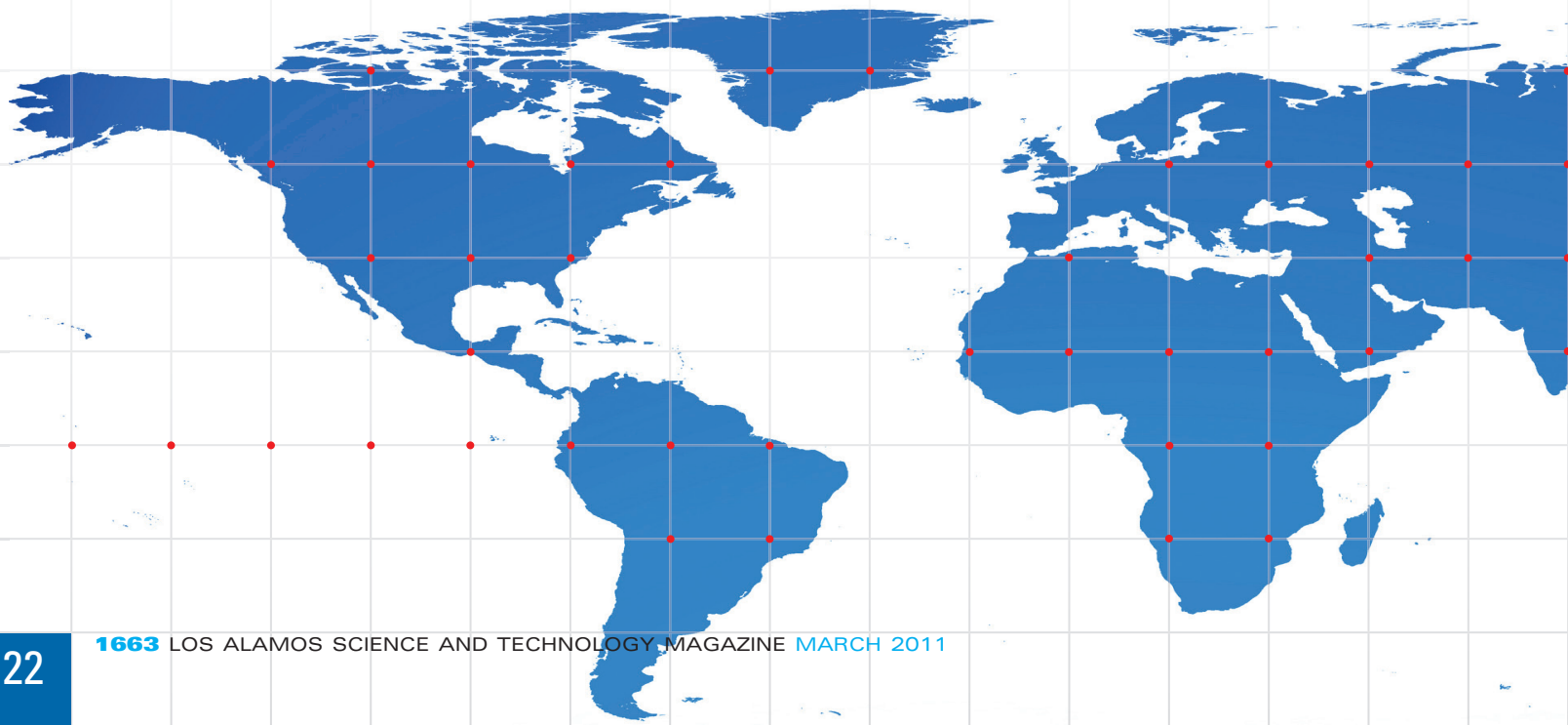
**Hawkins:** We also have a nuclear forensics team principally comprised of staff from the Nuclear Chemistry Group. The term "nuclear forensics" pertains to their use of scientific methods—including radiochemistry, mass spectroscopy, and microscopy—to develop specific assessments of activities involving nuclear materials and weapons. Roots for these methods were pioneered here at Los Alamos, going back to a time when we tested nuclear weapons by detonating

them. Our nuclear forensics techniques are very powerful. For example, a forensic analysis can be derived from about 0.00000001% of the fissions produced by a 1-kiloton device. This radiochemical assessment can provide information on the device design, sophistication, and performance. It can also provide insights into the possible source of the fissile materials involved. But, since the debris cannot tell us whether or not these materials were stolen, nuclear forensics alone will not allow us to say who built the device or who detonated it. That information has to come from intelligence and other techniques—again, areas where Global Security (GS) plays an important role.

**1663:** Nuclear forensics. It sounds like CSI on steroids. What do you do with the information you collect?

**Rees:** The work that the Lab does in these areas is highly respected and sought after. Because of our expertise in weapons design and weapons infrastructure, we provide unique insights into foreign weapons programs. It is highly unlikely that any would-be proliferators would go down paths that we have not already explored, or at least thought about. Because of this experience, we help our government partners understand the technical underpinnings of the threats as well as the detection and prevention of those threats.

However, it must be emphasized that we don't make policy. We support, using science and technology, policy development by providing knowledge and advice to the appropriate federal authorities. We know that technical support is an important component used by those authorities as they set priorities. As such, we offer our best technical advice, knowing that it will be only one component in the policy makers' decision space. So if the government tells us to find a way to detect a nuclear





explosion down to a certain level, then we will put the best technical minds in the country to work on that problem—even if that goal exceeds our current understanding of the science involved.

Using this paradigm in 1943, this Laboratory designed, fabricated, tested, and built the world's first nuclear weapons—in the short time frame of just two years. In GS, we're working hard to continue that tradition of science in the national service in our areas of responsibility.

**Hawkins:** And those GS areas of responsibility span the gamut of science and technology beyond those associated with nuclear proliferation. Because the Lab has such a wide breadth of outstanding talent, our expertise has been in rising demand. As a result, we now have more customers who present us with new, interesting challenges. Thus, the Laboratory and the GS directorate provide support not only to the National Nuclear Security Administration's nonproliferation mission, but also to the Department of Defense (DoD), Department of Homeland Security (DHS), Department of Justice, and to the Office of the Director of National Intelligence and the broader intelligence community.

**1663:** What are your other focus areas?

**Rees:** Ensuring global security requires that GS be involved in several areas besides nonproliferation. These include support to warfighters, the U.S. intelligence community, event response, counterterrorist tactics, resilient global infrastructure, and space science. However, they often overlap. Our work in space science is an example. Since the earliest days of satellites in the 1960s, the Lab has been at the forefront of space-based monitoring—looking for nuclear detonations with our space-based assets. One of

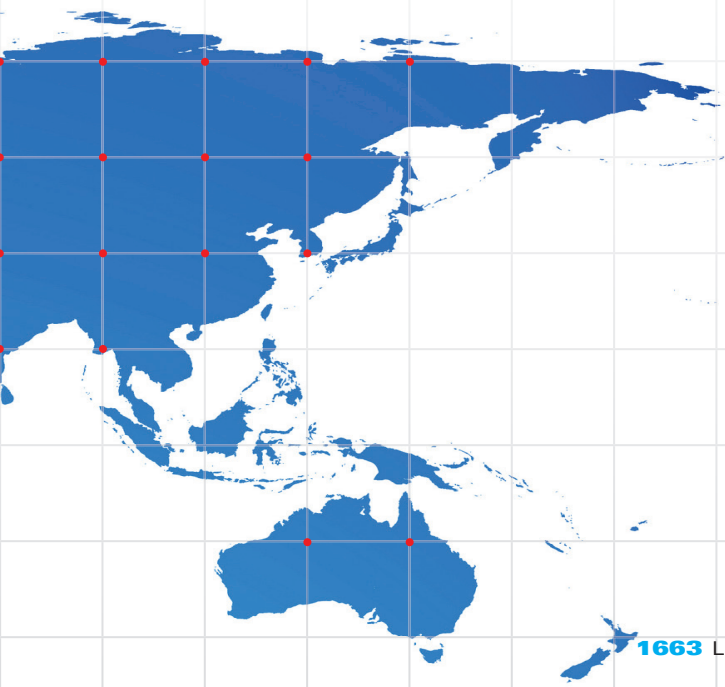


the core components of space-based security has always been nonproliferation. The Laboratory was a key player in developing the first monitoring satellites, called Vela, which means “watch vigilantly” in Spanish. From the first Defense Advanced Research Projects Agency satellite program to the NUDET (nuclear detonation detection) missions flown today, Los Alamos did each and every one, in partnership with Sandia National Laboratories.

In addition, the Lab is at the cutting edge of space-based science. For example, we pursue new computing and analysis capabilities for the evolving and challenging fields of space situational awareness and space weather studies.

**Hawkins:** Note that we made the cover of *Science* for our work with NASA's Interstellar Boundary Explorer (IBEX) mission. IBEX was able to discover new fundamental properties of the heliosphere—the bubble created by the Sun that the solar system lies within. Solar materials, with characteristics we hadn't expected, have accumulated at the outer fringes of the heliosphere forming an arc-shaped ribbon of high-pressure material that appears to be piled up there after being ejected from the Sun. IBEX makes it possible to construct a more comprehensive sky map of our solar system. The map is going to be completely different from what we thought it would look like, fundamentally changing the way we view the interactions between our galaxy and the Sun. This technology is also important to global security, because in using IBEX sensors and data interpretation methods to model the heliosheath, we are also suggesting to others, who might be planning to use space to carry out some nefarious experiment, that we might be able to see their experiment. Showing and knowing are both elements of deterrence.

**Rees:** We've developed over 1400 sensors and 400 instruments for 60 satellites and spacecraft that have provided researchers with invaluable information. This information spans the gamut from finding the brightest source of light in the universe to providing the first confirmatory evidence of water on the surfaces of the Moon and Mars. The planet Mercury is next. Because of these and other discoveries, we are internationally recognized for our



contributions to space science. Said another way, our space people rank tops in citations, a factor that measures both the productivity and impact of scientific publications. I'm a recovering academic, and to me, the top spot in citations is a big deal.

**1663:** What is "space situational awareness"?

**Hawkins:** Well, the term is self-defining. It means integrating and analyzing data from space surveillance, reconnaissance, intelligence gathering, environmental monitoring, and orbiting cybersystems to understand both natural and anthropogenic threats to our important space-based assets.

**1663:** What can you tell us about the Lab's role in intelligence gathering?

**Rees:** Although we don't elaborate on it, our important work in this area is focused on intelligence analysis, integration, and exploitation. We work closely with the DoD, DHS, and other federal agencies on their intelligence-related challenges. Our clients present us with a problem, and we provide the best science-based options and interdisciplinary solutions possible in the fastest times imaginable. And depending upon the nature of the problem, that solution could take a couple of hours up to a couple of decades. We provide our clients with hardware, software, analysis, modeling and simulations, and technical processes and techniques. Our goal is to provide the means to meet a mission with the least risk to the mission, to the people, and to the environment while being the most efficient and cost effective. We have provided effective solutions that had been deemed by others to be impossible.

**Hawkins:** Our clients appreciate our work and they keep coming back to us for more. And by "us" I don't mean just PADGS. Remember, global security is a core mission of the Lab for a reason.

**Rees:** The fact is that we depend on the entire Lab and its resources and talents to meet our customers' needs, because we cannot necessarily predict the nature and dimensions of the important problems we are being asked to address.

**1663:** So it's an interdisciplinary team effort.

**Rees:** Always. Note, too, that often it also demands partnering with other organizations to meet the nation's requirements. One of the top factors in determining how to approach a specific mission is to first ascertain what part of the solution space resides in the central capabilities of the

Laboratory. We then seek external partners to complement these areas and develop the team that will design the best solution for the government.

**1663:** Would you elaborate more on our work to support our warfighters?

**Hawkins:** Conventional warfare continues to evolve technologically, getting ever more high-tech and cyber-dependent. The nation needs the Lab to keep current and, better yet, stay ahead. But it sometimes requires ever-better science and technology just to overcome even relatively primitive threats, like the homemade improvised explosive devices, or IEDs, that account for many of the casualties in the current war in Afghanistan. The DoD comes to the Lab when the complex science and technology existing here is needed for warfighter support. For example, GS was instrumental in developing the AngelFire System of advanced optics and computers that provides broad-area, real-time, high-resolution surveillance of our opponents.

The Lab is also working on developing entire new classes of defensive weapons using free-electron lasers. And we're engaged in research on alternative energy sources for military (and nonmilitary) applications.

**Rees:** That's because our military complex is among the world's largest energy consumers. Three-quarters of that is petroleum-based energy. The costs of petroleum, along with its transportation and storage and the impact its use has on the environment, are huge burdens. Napoleon was right in saying that an army marches on its stomach, but today we can add that it rides and flies on its petroleum. Imagine the positive impact we would make if we could reduce even a fraction of that amount!

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*The fact is that GS depends on the entire Lab and its resources and talents to meet our customers' needs.*  
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**1663:** How does GS support countering terrorist tactics?

**Rees:** Deterrence and response, either preemptive or retaliatory, are difficult. A terrorist with a weapon of mass effect may represent an ill-defined and relatively small organization with no significant infrastructure using destructive devices kludged together in someone's garage.



But we're the come-to Lab when it comes to dealing with really tough challenges. Our customers, like the DHS, rely on us to provide the best science and technology to predict, deter, and help mitigate terrorist threats. We provide intelligence gathering tools and data analysis. We have extensive capabilities to design and fabricate conventional, micro-, and nanoscale sensors, power sources, beacons, and antennas to help tag, track, and locate persons of interest.

Another aspect of countering terrorism involves deploying technologies to diminish the burden to our citizenry associated with certain security measures. Our MagViz technology, and next-generation CoilViz technology, can distinguish threatening liquids from the harmless shampoos and beverages that travelers want to take aboard an aircraft. This technology would increase security while both enabling innocent travelers to take, for example, their water bottles, on board and to board more quickly.

**Hawkins:** There has been a lot of press coverage of the new "show-it-all" images in use at a growing number of airports. We believe we could use our genetic algorithm technology to analyze the image and thereby take the human viewer out of the issue. Then, if we could only find a technology that would allow us to keep our shoes on, we'd have it made! That is, of course, until the next threat evolves.

**1663:** What is a "weapon of mass effect"?

**Hawkins:** We make a distinction between weapons of mass destruction (WMDs) and mass effect (WMEs). You can think of a WMD as being a subclass of WMEs, which impact a wide area but can involve relatively little physical destruction. Neutron bombs or "dirty bombs" or deadly viruses are good examples of weapons with mass effect but little physical destruction, whereas a nuclear bomb has both a mass effect and mass destruction. Said another way, we are distinguishing between the destruction of a large city block with adjacent impact and the destruction of a large city. Dealing with WMEs is an important focus area within GS.

**Rees:** Note that a WME might cause very few or even no casualties but still be devastating. For example, a broad cyberattack could result in relatively few casualties but cost the nation trillions of dollars to recover from.

U.S. officials believe there is a high probability of an attack using a WME in the near future, somewhere in the world. No matter where it occurs, no matter if it's perpetrated by a terrorist organization or a failed state unable to secure its WMEs, this event will have a major impact on global



security, and by extension, our national security. The Lab has unique skills and capabilities in chemistry, radiology, materials science, explosives science, etc., under its roof to assist our nation in dealing with the WME threat. We have the science and technology, and will continue to improve them, to monitor, identify, predict, interdict, defeat, and when needed, mitigate WME threats.

**1663:** So GS is also focused on developing event responses?

**Rees:** Of course. Some events are avoidable but we must be prepared for a worst-case scenario. Being ready to reduce the consequences of such attacks is an essential element of deterrence.

**Hawkins:** Our customers, like the DHS's National Infrastructure Simulation and Analysis Center (NISAC), rely on us to provide the best science and technology to help mitigate events, whether natural or anthropogenic in origin. We model events and event responses for NISAC using everything from high-performance computing to individual subject-matter experts. We provide the most intelligent and effective suite of response solutions for international, national, state, and local decision-makers to have on their shelves ready and waiting should an unfortunate, or unthinkable, event happen. In addition, we train rapid responders, develop mitigating technologies, and provide analysis and supportive resources during ongoing events.

**Rees:** So, getting back to your original question, GS is a PAD with a new name, but its fundamental missions are not new to the Laboratory. It's just that our responsibilities and challenges in keeping the nation secure have gotten considerably larger and more complicated. The "Global" in our name reflects this growth. ❖

— Clay Dillingham

# SPOTLIGHT

## Bounding the Oil Spill

Last May, Los Alamos ocean scientist Mathew Maltrud was taken aback as he viewed the results of his first supercomputer simulation of the Deepwater Horizon oil spill. The virtual dye he was using to trace the oil's path had been picked up by the swift Loop Current, exited the Gulf of Mexico, and then joined the powerful Gulf Stream flowing up the coast of North America and into the open Atlantic—all within a matter of weeks.

The speed of the currents was something of an eye opener. Having recently completed a global ocean simulation spanning more than a century, Maltrud was accustomed to taking a longer view of events. But at the time, less than a month after the real spill began, the simulation raised the possibility that the oil might wash

up on the eastern seaboard or perhaps even reach the coastlines of Europe. The fact that crude oil was still gushing from the seafloor at an unknown rate, with no end in sight, only added to concerns about where the oil might go and when it might get there.

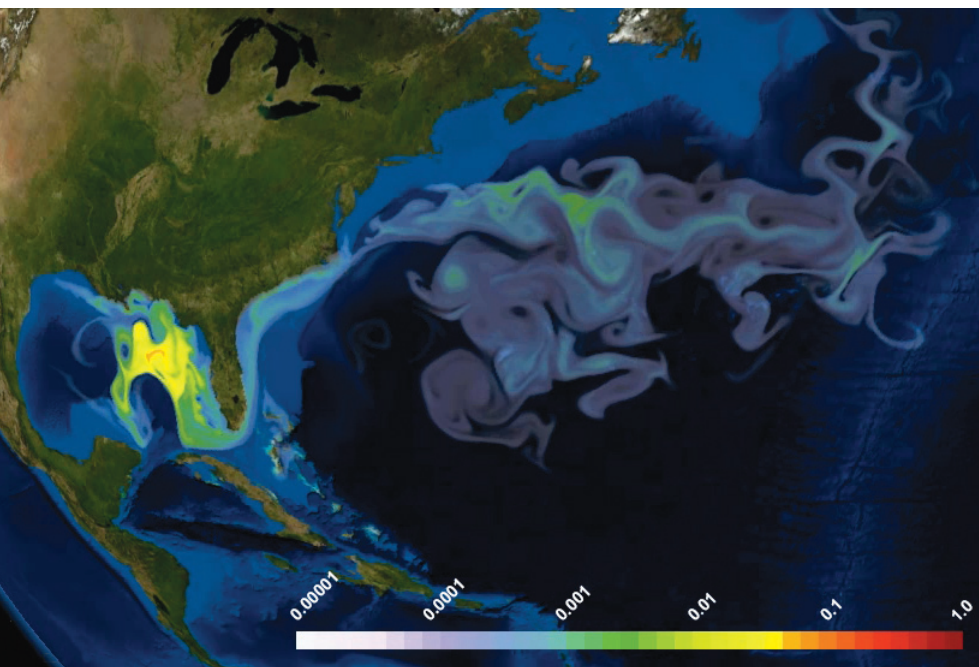
While that first simulation was dramatic, it was not a forecast. It depicted just one possible pathway for the oil. Currents in the Gulf of Mexico are too complex to be accurately predicted more than a couple of weeks into the future. On longer time scales, the dominant feature of the Gulf—the clockwise Loop Current—shifts position over hundreds of miles and sheds eddies at irregular intervals. Such eddies typically travel west and can last anywhere from weeks to months. Along with local winds, these factors alter the overall ocean dynamics in the Gulf in unpredictable ways.

So to get a handle on the long-term fate of the oil, Maltrud and Los Alamos colleague Phil Jones, with collaborators from the National Center for Atmospheric Research and the University of Kiel in Germany, decided to take a statistical approach. Dozens of simulations were carried out, each beginning with a different but realistic Loop Current scenario, as a way to bracket the ever-changing conditions in the Gulf. When all the simulations were complete, the team averaged the results of the individual simulations to establish where the oil would likely travel.

The scientists used the Parallel Ocean Program, the state-of-the-art ocean circulation model developed at Los Alamos, which divides the world's oceans and seas into computational cells covering a tenth of a degree of longitude and latitude, small enough to rigorously model the Loop Current and associated eddies. The simulations were run on the state of New Mexico's Encanto supercomputer and Oak Ridge National Laboratory's Jaguar supercomputer. On Jaguar, the second fastest computer in the world at the time, each simulation took two or three days to complete.

To simulate the spill, virtual dyes were continuously added at multiple depths above the Macondo well site of the spill for either two or four months, and the simulations were continued for a total of six months or a year. The virtual dyes served as passive tracers, much like food coloring, possessing none of the physical characteristics of real oil. By neglecting coagulation, surface-slick formation, decay, and other processes that would tend to reduce the spread of oil, the team could interpret their predictions as an upper bound for the oil dispersal.

Even with this caveat, the researchers were able to draw a number of timely conclusions that have held up well. No oil was expected to reach the shores of Texas, Mexico, Cuba, or the Bahamas within six months of the initial spill. While some



*Modeling the Deepwater Horizon oil spill: The dispersion and dilution of a virtual dye 180 days after the initial spill, as predicted by one of an ensemble of simulations. The color scale shows the dilution factor, the ratio of total amount of dye in the water column to the amount injected at the source.*



fraction of the oil would almost certainly escape the Gulf, it would be so diluted that large amounts would be unlikely to wash up on the eastern coast of the U.S. or Canada. Oil would be even less likely to reach Europe in detectable amounts. The finding that virtual dye injected below a depth of 800 meters remained within a few hundred miles of the spill is consistent with reports of deep underwater oil plumes lingering in the northern Gulf region.

Despite a brief media flurry when released to the public last June, these conclusions were at least somewhat reassuring in that they suggested that the oil from the Deepwater Horizon spill, which would become the largest marine spill in history, was not likely to cause major deleterious effects beyond the Gulf. This work was published in *Environmental Research Letters* in August 2010 and serves as just one example of peer-reviewed research that addressed the Gulf oil spill by harnessing capabilities developed for other Department of Energy missions. At the direction of Secretary of Energy Steven Chu, an intense multi-Laboratory effort was formally made to expedite the capping of the Macondo well.

—Craig Carmer

## Making Waves

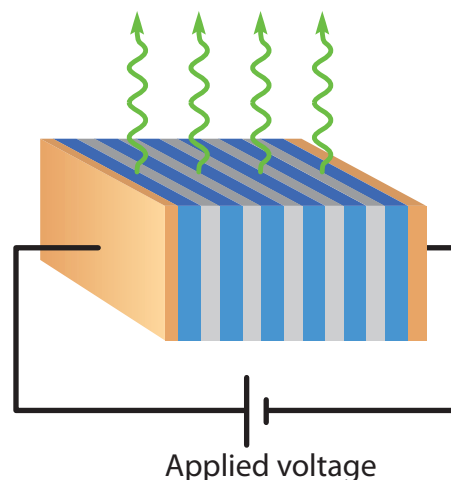
Electromagnetic radiation can be divided into many frequency bands, such as x-ray, visible light, and radio, and technologies have steadily emerged to make use of most of these frequencies—except for radiation having an oscillation frequency in the terahertz range. With wavelengths of a fraction of a millimeter, shorter than microwaves and longer than infrared, terahertz waves are comparatively difficult to create, manipulate, and detect.

Los Alamos scientists Nathan Moody, Lev Bulaevskii, and Vitaly Pavlenko are pursuing new methods that may make this type of electromagnetic radiation more accessible. If their research into a practical

terahertz source continues to prove successful, it could open up a wide range of important new applications, owing to the novel properties of these waves. Terahertz waves can pass through many materials (such as paper, wood, plastic, cloth, and others), yet they are harmless to living tissue. They can also interact with everyday molecules to “see” what an object is made of. Thus, they could potentially improve security and medical scans by imaging something hidden, for example, inside a container or beneath the skin, and identifying that hidden object’s chemical composition. Other potential applications abound, including improvements in high-speed terrestrial and satellite communications.

Unfortunately, existing electronic components can’t keep up with terahertz frequencies’ trillions of oscillations per second because of the finite electron mobility in conventional materials, so new materials and new techniques are needed. Moody and his team are exploiting a quantum mechanical phenomenon called the Josephson effect as the basis of their approach. When a steady voltage difference is applied across a Josephson junction—a thin electrical insulator sandwiched between two superconducting slabs—an electrical oscillation is produced: pairs of electrons repeatedly jump through the insulator in a quantum mechanical process called tunneling. As it turns out, generating terahertz-frequency oscillations capable of producing the desired waves requires only a small applied voltage, about one-thousandth of the voltage provided by an ordinary AA battery. Additionally, the effect is tunable: a different applied voltage yields a different terahertz frequency.

The problem, however, is scale. A single Josephson junction generates only about a trillionth of a watt of terahertz power, which is far too weak to be useful. A billionfold improvement is needed, but trying to manufacture a very large array of junctions would result in insurmountable engineering challenges. Instead, Moody’s



*Schematic for a Josephson junction stack, with insulating layers (gray) sandwiched between superconducting layers (blue). An external, applied voltage difference generates an alternating current in the stack to produce terahertz waves.*

team is leveraging an existing effect in a crystalline film called BSCCO (pronounced “bisco”) to act as an assembly of about 10,000 atomic-scale Josephson junctions, packed within the size of a single sub-millimeter wavelength—close enough that their individual oscillations synchronize and give rise to coherent, laserlike emission.

Within the complex atomic structure of the BSCCO ceramic, a thin layer of bismuth, calcium, and lanthanum oxides serves as the Josephson junction’s insulator, while a copper layer serves as its high-temperature superconductor. (“High temperature” in this context is about 200 degrees below zero Celsius, which is attained with relatively inexpensive, off-the-shelf cryocoolers.) Because the atomic layers must be oriented the right way for the superconducting current to flow across the insulating layers, Moody’s team is pioneering new ways to either grow or modify the material, essentially laying down a row of nanometer-sized layers across the surface of a substrate (like books on a bookshelf), rather than the more typical approach which yields a vertical stack (like books stacked in a pile). They use either pulsed-laser deposition to grow the crystal on the substrate or pregrown crystals that

are mechanically bonded and then etched to achieve the desired row geometry. Use of established manufacturing techniques, such as argon ion milling, might ultimately pave the way toward large-scale production at a reasonable cost.

Already, the team has produced several device designs based on Bulaevskii's foundational work, and is now engaging Los Alamos materials scientists to evaluate and improve their sideways BSCCO orientation process. Within a year, they expect to have a working demonstration of the fundamentals of a tunable terahertz source. The design of this source may also inspire or complement other functional components—filters, modulators, mixers, amplifiers, detectors, and so on—needed to assemble an entire terahertz system for a specific mission or application. **LDRD**

—Craig Tyler

## Do the Time Warp

Researchers at Los Alamos National Laboratory have made a fundamental breakthrough in time travel—on the Internet, that is—by building a bridge to the World Wide Web as it existed in the past.

Herbert Van de Sompel and his team of computer and information scientists at the Los Alamos Research Library and Old Dominion University have written a new technical specification that embeds the concept of time within the global explosion of information that we call the Web. The new specification is part of the team's recently proposed information framework, dubbed Memento, which endows the Web with a built-in mechanism for version control of Web pages, databases, and other digital resources. In practice, Memento turns the Web into an online playground for would-be time travelers.

Hitching a time ride with Memento is easy, thanks to a new plug-in that the team has developed. When installed in a Web browser, the Memento plug-in provides

a drop-down calendar for selecting a time destination. Want to relive the excitement of the 2004 World Series? Turn the Memento calendar back to October 27, 2004, click on a link to *The Boston Globe*, and away you go. After transporting you to an archived version of a Web page, Memento maintains the illusion of the past: hyperlinks embedded within the destination page send you to archived Web pages from the same time period.

Before this seemingly simple idea could be implemented, the Memento developers had to teach the Web how to keep track of time. As it turns out, the Web has a bad case of amnesia. When a Web page is updated with new information, the updated version typically inherits the address of its previous incarnation. This is a sensible idea, one that avoids breaking all the existing links to the page from the Web at large. But the cost of this stability is memory loss—older versions are too often left unlinked, abandoned on Web servers to the forces of bit rot and digital obsolescence.

Memento solves this problem by adopting the notion of time as a version indicator and inserting it into the process of content negotiation, the behind-the-scenes digital exchange that takes place between a browser requesting a Web page and the server on which the page resides. This approach allows the version of the page returned to the browser to be matched as closely as possible to the user's time preference. The processes underlying the Memento framework are executed using HTTP primitives, the basic elements of the standard Web protocol. While the scope of other versioning approaches is limited by their use of proprietary syntax, Memento speaks a global language that opens the entire Web to version control.



*Memento is a new information framework for the Web that turns back time by providing a direct link between current and archived versions of Web pages.*

Time travel with Memento works only when someone has had the foresight to archive a requested Web page. Pockets

of memory exist throughout the Web, for example, in the version histories maintained by Wikipedia and the snapshots of the Web kept as cultural records by preservation groups such as the Internet Archive and the Library of Congress. Memento provides a direct path between a current Web page and earlier versions stored in these repositories, thus eliminating the detective work of clicking through a cascade of links to find archived information.

Tim Berners-Lee, who invented the Web in the early 1990s, and other Web luminaries have taken notice of Memento and offered encouragement. And the archivists love it. The Library of Congress provided the initial seed funding for Memento and has contributed an additional \$1 million for further research, development, and outreach. Memento team member Robert Sanderson recently met with the General Assembly of the International Internet Preservation Consortium in Singapore, where he received commitments to implement Memento from the national Web archives of several countries. The entire team recently beat out stiff international competition to win the 2010 Digital Preservation Award.

Van de Sompel believes that Memento has the potential to profoundly alter the way we perceive and interact with the Web. "By increasing awareness of the Web of the past, Memento will help expand our collective digital memory," he says. It can also be a lot of fun. See for yourself by downloading the



free Memento plug-in for the Mozilla Firefox browser at [www.mementoweb.org](http://www.mementoweb.org). An application for Android phones is available through the same site, and an iPhone application is on the way.

—Craig Carmer

## Warming Oceans, Shrinking Ice

The fate of low-lying coastal cities and island nations around the globe could depend on the future of the massive ice sheets covering Greenland and Antarctica. The water locked up in Greenland's roughly 700,000-cubic-mile ice sheet is enough to raise the global sea level by 23 feet. Western Antarctica's ice sheet could contribute another 15–20 feet. Scientists thought these ice sheets would melt over millennia, if at all, until recent observations showed that both have been losing ice mass at an increasing rate since the early to mid-1990s. Is this trend likely to continue as the planet warms, or are these changes due to normal variations in climate?

The observational answers won't be in for another decade or more, and the best computer models for climate prediction can't give realistic answers either—not yet. Traditional climate system models compute ocean circulation, sea ice formation and melting, and atmospheric circulation, and they predict how those processes would change in response to rising temperatures. But until recently, ice sheets have been treated as stationary features of the planet.

That's about to change. Scientists working on Los Alamos's Climate, Ocean, and Sea Ice Modeling project, who have contributed both the ocean and the sea ice components of the widely used Community Climate System Model, are now building a new component that will track the dynamics and melting of ice sheets.

The new model component will account for the two main mechanisms of ice loss to the oceans. One is summertime surface melting, a fraction of which flows into large vertical shafts, called moulins, to the base of the ice sheet. This process lubricates the base of the ice sheet and facilitates faster sliding toward the ocean. The other main mechanism of ice loss is through outlet glaciers and ice streams, rivers of fast-moving ice that flow directly into the ocean.

Until the early 1990s, Greenland's outlet glaciers appeared to be flowing at fairly constant speeds, but during the last decade, they mysteriously sped up, some more than doubling their speed. Surface melting increased over the same period. Was an increase in meltwater lubrication causing these glaciers to slide more easily over the bedrock on their way to the ocean?

Surprisingly, the majority of the evidence points not to the lubricating effects of meltwater but to warm ocean water. Over the past decade, warm ocean water has been reaching the fronts of the outlet glaciers, which protrude into the ocean and float above the bedrock. Warm water has triggered the melting and disintegration of these floating ice tongues, as well as melting near the grounding line, the boundary between grounded and floating ice. Both have the effect of "uncorking" the outlet glacier and allowing it to speed up. Some, but not all, of these glaciers have since slowed down again as ocean circulation patterns have shifted.

Los Alamos researchers William Lipscomb, Stephen Price, and Xylar Asay-Davis are beginning to model these effects. They aim to simulate the dynamic interplay between outlet glaciers and ocean circulation and to understand how that interplay affects the loss of land ice to the oceans. If all goes well, this work will contribute to more realistic predictions of sea level rise by 2100, when the United Nations' Intergovernmental Panel on Climate Change tells the world what to expect for the next century. **LDRD**

—Necia Grant Cooper



Iceberg broken off from Greenland's Ilulissat Glacier.  
PHOTO CREDIT: JAMES BALOG / EXTREME ICE SURVEY



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